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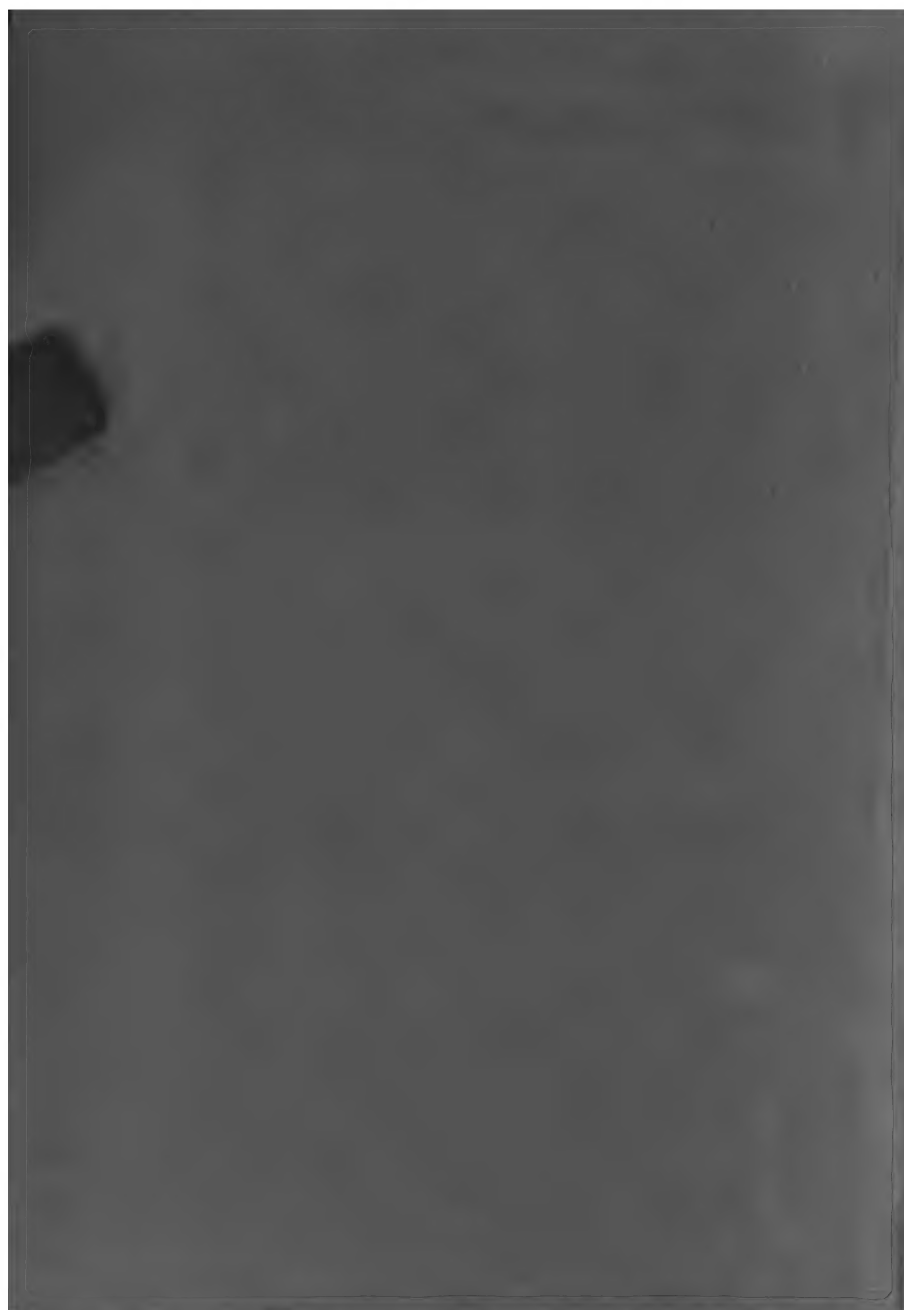
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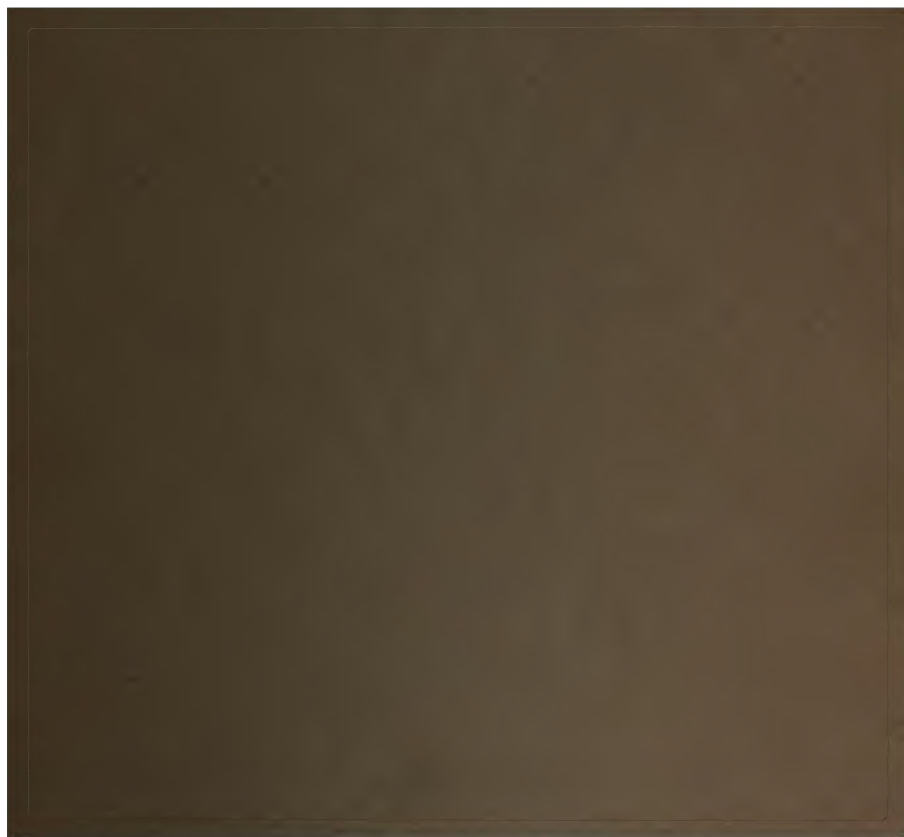
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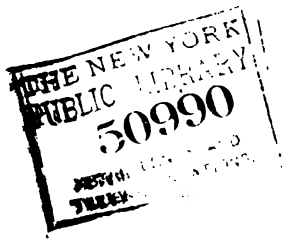
OF THE

IRON AND STEEL INSTITUTE.

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PROCEEDINGS
OF THE
IRON AND STEEL INSTITUTE.
—
LIVERPOOL MEETING, 1892.
—

TUESDAY, SEPTEMBER 20TH.

THE AUTUMN MEETING of the INSTITUTE was opened on the forenoon of September 20th at St. George's Hall, Liverpool, Sir FREDERICK ABEL, K.C.B., D.C.L., F.R.S. (President), occupying the Chair.

RECEPTION OF THE INSTITUTE.

HIS WORSHIP the MAYOR of LIVERPOOL (JAMES DE BELS ADAMS, Esq.) said that, as Chief Magistrate, and as President of the Local Reception Committee, he heartily welcomed the Iron and Steel Institute to the city, and he hoped that the arrangements made by the Committee would be such as to merit the approbation of the members. It was in the year 1879 that they last visited Liverpool, and they then inspected several places of interest in the locality. On the present occasion, the programme included visits, not only in Liverpool, but also to other places of interest in the neighbourhood. Arrangements had been made to see the Manchester Ship Canal, and those who would like to go as far as Vyrnwy would be able to see the admirable works carried out there for the supply of water to the city. Again he desired, in the name of the Committee, heartily to welcome the members to Liverpool, and he hoped that during their stay in

the city the arrangements made for their comfort and convenience would meet with their approval.

The PRESIDENT said that, on his own behalf, and on behalf of his colleagues on the Council and the members of the Institute, he desired cordially to thank the Mayor for his hearty words of welcome. They had had the pleasure of visiting the town thirteen years ago, and they were now able to notice the vast progress that had been made in every direction since that time. For Liverpool had always been most intimately associated with the revolutions that had been made from time to time during the last fifty years in the art and science of construction, and in applied mechanics. Thirteen years ago, when they had the pleasure of listening to and discussing a variety of excellent papers, there was one of especial interest by Mr. J. A. Picton on the progress made in the application of iron and steel to constructive purposes, and those who would visit the docks a day or two hence, and admire those magnificent vessels which were rivalling the now classical *Great Eastern* in size, and greatly excelling her in speed, would be able to recall the interesting statement made by him, that the first sea-going iron ship was built by James Hodgson in the year 1844 in Liverpool—a ship of 522 tons burden. Since that time what rapid strides had been achieved! For a time no progress was made; but, as Mr. Picton had pointed out, all of a sudden, as by an impulse of common consent, wood was discarded and iron ruled the day; and as iron ruled the day then, or shortly afterwards, so did steel rule the day now. No better place than Liverpool could have been chosen for witnessing illustrations of all descriptions, great and small, of the great variety of purposes to which iron and steel could be applied. They had all looked forward with great pleasure to the present meeting. He thanked the Committee heartily for the arrangements made for their comfort and pleasure; and they were perfectly sure that among the many interesting meetings which the Institute had held, not the least interesting would be the one now about to commence.

The Minutes of the previous meeting were then read, confirmed, and signed by the President.

NEW MEMBERS.

Messrs. J. S. SIMPSON and E. G. TOSH were appointed scrutineers of the voting papers, and reported, on the completion of their scrutiny, that the following candidates had been elected members of the Institute:—

BELLACOSA, NARCISO PING DE LA.....	Madrid.
BELLHOUSE, EDWARD LLOYD W.....	Sheffield.
BOBRSYK, GUILLERMO.....	Spain.
CAINE, WILLIAM SPROTSON, M.P.....	London.
CLAYTON, WILLIAM WIKELEY.....	Leeds.
CRADOCK, GEORGE.....	Wakefield.
CRAWFORD, JAMES.....	Werkington.
DELANO, FREDERIC A.....	Chicago.
FACKENTHAL, B. F., JUN.....	Riegelsville, Pa.
FRANK, JULIUS.....	Ems, Germany.
GREATHEAD, JAMES HENRY.....	London.
GRIFFITHS, ERNEST.....	Griffithstown, Mon.
HORNUNG, CHARLES.....	Melton Mowbray.
JONES, GREVILLE TYNDALL.....	Middlesborough.
PATTISON, JOHN ALFRED.....	Naples.
PICKFORD, JOSEPH JAMES.....	Sheffield.
SANITER, ERNEST HENRY.....	Wigan.
SUTHERLAND, DAVID ALEXANDER.....	London.
THOMAS, JOHN.....	Llangennech.
WELLS, W. E.....	Rotherham.

THE PRESIDENT'S ADDRESS.

It is a judicious custom with us, having regard to the large amount of business to be accomplished generally at our Autumn meetings, that the introductory observations of the President should, on those occasions, be brief. In limiting myself, therefore, to a few remarks appropriate to the occasion, allow me in the first instance to remind the members of the Iron and Steel Institute that the year of our former visit to Liverpool was one of especial interest in the annals of this Association, for it was in that year that the successful results, and the first really practical achievements, in the elimination of phosphorus from pig iron during its conversion into steel, were communicated to the Institute on the occasion of the first meeting presided over by one of the most eminent of our practical authorities on iron and steel—whose comparatively early death we all deplore—Mr. Edward Williams, of Middlesbrough, who filled the office of chairman at the meeting in Newcastle-on-Tyne which led to the existence of our Institute, and who was the very first to institute practical and successful experiments with the Bessemer converter by simply following the statements embodied in that memorable paper read at the British Association Meeting at Cheltenham in 1856.

The most prominent of the communications made to the Institute at its spring meeting in 1879 were those of Thomas and Gilchrist, of Snelus, and of Windsor Richards, on the removal of phosphorus from iron, and they gave rise to a very instructive discussion, which was resumed in the autumn at Liverpool, *à propos* to a paper on the same subject by M. Pourcel of Terre-Noire.

A subject was incidentally dealt with in 1879 by Mr. Snelus, in the paper just alluded to, which has assumed considerable prominence during my presidency, namely, the removal of sulphur from pig iron during the production of steel from the latter, which he showed to be concomitant with the elimination of phosphorus in the converter when a basic lining was employed,

accompanied with the maintenance of a thoroughly basic slag. Our information on this subject was not added to until Mr. Massenez gave us his interesting and instructive paper on the important results attained at Hoerde in the application of an observation which appears to have been originally made by Caron a good many years ago, that manganese was an efficient desulphurising agent, the sulphur being carried into the slag as sulphide of manganese. At our Spring meeting this year, we received from Messrs. Ball and Wingham a description of the results of laboratory experiments, in which potassium cyanide and potassium ferro-cyanide were employed in conjunction with sodium carbonate as desulphurising agents, sodium carbonate and sodium oxide being also tried alone. The advantages attending the employment of the cyanides did not appear to be made out conclusively, and although a very considerable reduction in the proportion of sulphur was effected in some experiments, complete desulphurisation was only attained by the auxiliary employment, towards the close of the process, of a small quantity of ferro-manganese, a result which provoked the criticism, on the part of Mr. Massenez, that it might have been more simply attained by the use of ferro-manganese alone.

On the present occasion we shall have before us, in connection with the subject of the removal of sulphur, a series of experiments carried out by Mr. Saniter, the results of which seem to demonstrate that calcium chloride (which can be obtained cheaply and in great abundance as a by-product of certain alkali works) is a very efficient desulphurising agent, and this conclusion receives strong support from the results described by Mr. Stead in an interesting paper which he has prepared for our instruction, and which combines a *résumé* of previous work by various investigators, and an examination of the value of several desulphurising agents, with an account of his own experiments on this subject. These two papers should elicit a very interesting discussion.

It cannot fail to be a source of rejoicing to all who are attending this meeting that Sir Lowthian Bell, after his recent heavy labour in the interests of this Institute, which have resulted in the safe delivery of his latest child, the special American volume, has found time and inclination to prepare for our information a paper

which, to judge from its suggestive title, is destined to excite great interest, as dealing with the inauguration of a new episode in the marvellous history of the utilisation of waste products. All who have followed the development of the basic process will remember the important part played in the rapid extension of its application in Germany by the utilisation of the phosphatic slag for agricultural purposes, and we have been thus in a measure prepared for Sir Lowthian Bell's revelations regarding the agricultural value of by-products from the blast furnace.

Ironmasters and manufacturers of steel will alike welcome the further achievements of Professor Roberts-Austen in the direction of a thoroughly practical application of his system of autographically recording the continuous temperature-indications afforded by thermo-junctions, which have been so successfully applied to the registration of high temperatures. Sir Lowthian Bell informed us at our last meeting that he had made successful use of platinum and platinum-rhodium thermo-junctions for obtaining records, in a central laboratory, of the temperatures in the hot-blast mains at the Clarence Iron Works, and the inquiries made of Professor Roberts-Austen since then, by ironmasters, have led him to develop and simplify his recording arrangements, so that the temperatures actually existing in mains, exit-gases, &c., in different distant parts of the works, may be expeditiously ascertained and recorded at a central station. The result of his successful labours in this direction will assuredly be highly valued and extensively applied.

The continuously progressive expansion, within the last four years, of our knowledge regarding the influence exerted by other metals, and by certain non-metals, upon the mechanical and physical properties of iron and steel, which has already been fruitful of practical results, could not be better illustrated than by the most comprehensive and instructive monograph on the alloys of chromium and iron which Mr. Robert Hadfield has prepared for this meeting; it not only furnishes an excellent digest of the history of this branch of a subject, to the study of which Mr. Hadfield has already so successfully devoted himself, but it also gives the results of a systematic series of mechanical experiments, carried out, chiefly by himself, with a number of iron-alloys in which the proportion of chromium ranges from 0.2

of 1 per cent. to 15 per cent. The results of experiments on the magnetisation and on the electrical qualities of several of these alloys, by Dr. Hopkinson and Dr. Bottomley, are included in the paper, appended to which is a report by M. Osmond, from whom the Institute has already received so much valuable information, giving the results of an investigation of the physical properties of Mr. Hadfield's chromium alloys, from which several very interesting conclusions are drawn, especially with regard to the conditions in which chromium is believed to exist in the annealed and unannealed alloys.

This paper, which doubtless will give rise to an important discussion, illustrates the successful application of methods of experimental investigation of quite recent elaboration into the properties of the metals and their relations to each other and to the non-metals;—methods replete with interest and importance, but the remarkable nature of which is at least equalled by the method of research now being applied by Professors Dewar and Fleming to the examination of the electrical resistances of pure metals, alloys, and non-metals.

The electrical conductivity of metals at low temperatures has been made the subject of study by several experimenters. Thus, Cailletet and Bouty examined, in 1885, the resistance, and resistance-change with temperature, of various metals at -100°C ., liquid ethylene being employed as the refrigerating agent. In the same year Wroblewski measured the electrical resistances of electrolysed copper, in the form of wire, at temperatures ranging from 100°C . to -100°C ., and also observed the comparative resistances of these wires at the critical point, the boiling point and the temperature of solidification, of nitrogen. But Professor Dewar, by the remarkable work upon which he has been of late engaged at the Royal Institution, has placed at the command of the physicist and chemist liberal supplies of a cooling agent, by the use of which much lower temperatures can be attained than those just referred to. By successive steps of refrigeration, with the aid of liquid carbonic acid, of ethylene, and nitrous oxide, and of simple mechanical arrangements, he has succeeded in producing liquid oxygen in such abundance that it has enabled him, and will enable others, to pursue methods of experiment and obtain results little dreamt of a few years

properties of metals; methods which may rival in their delicacy the greatest achievements of analysis or the most sensitive thermal methods of research. It is true that the materials and appliances required for the preparation of pure oxygen are costly, and that the operations are laborious; but there is no finality in such fields of experiment as this. Three or four years ago great labour and greater uncertainty attended the preparation of two or three drops of oxygen; now the appliances at the Royal Institution furnish liquid oxygen in pints; the process of production may, indeed, be said to be approaching one of manufacture, and some in this room may live to see the day when the history of liquid oxygen is a complete parallel to that of liquid carbonic acid, the preparation of which in small quantities, in my young student days, involved many hours of hard labour, while, on the other hand, it has now for years past been an indispensable article of commerce. Thus workers in pure science are ever placing fresh resources within the reach of those who labour to apply the results of scientific research to the uses of man.

THE MANUFACTURE OF IRON IN ITS RELATIONS WITH AGRICULTURE.

BY SIR I. LOWTHIAN BELL, BART., F.R.S.

I AM not going to speak this morning of the important service rendered by iron to agriculture, even when our corn was threshed with the flail, and when our land was ploughed by an implement formed chiefly of wood. Neither am I going to claim, from the farmer, an acknowledgment for our having furnished cheap materials, out of which the mechanical engineer has constructed a variety of labour-saving instruments for his use. The link which connects us with our food-producers, and upon which I am about to occupy a portion of your time this morning, belongs to chemical, and only incidentally to mechanical, science.

As is well understood, failure would attend any attempt to produce a crop from the moistened mineral matter which enters into the composition of the soil. For the purposes of fertility the presence of organic matter is necessary, the main object of which is to assist in the assimilation of the earthy substances which enter into the composition of what is known as the ashes of the plant. These are small in quantity, but are indispensable for the existence of vegetable life.

Not the least remarkable phenomenon in connection with the production of what may be regarded as the origin of all food is the enormous area from which plants have to gather their nutrition and, therefore, their substance. Towards this the soil contributes little or nothing, and it is from our vast atmosphere itself that all the carbon which enters, to the extent of 35 to 50 per cent., into most vegetable matter, is derived. This element, in the form of carbonic acid gas, is found in the air we breathe to the extent of only 4 volumes in 10,000, equal therefore to about $\cdot 016$ of carbon for every 100 parts by weight of air. Notwithstanding this mere trace, it has been estimated that in our atmosphere there is stored up more carbon than is contained collectively in the earth's surface in the solid form, in the bodies

is converted into water, leaving the combined nitrogen to escape as such, with the formation of little or no ammonia. If, however, the coal is heated in a closed vessel, air being excluded, the volatile carbon and its associated hydrogen chiefly pass off, as tarry matter, and the nitrogen, taking up hydrogen, is carried over in the form of the precious ammoniacal alkali so much wanted.

Coal, however, up to the earlier part of the present century was rarely submitted to the distillatory process just referred to. After this it occurred to Mr. Murdoch, exactly a hundred years ago, to light his house by gas so obtained. The discovery, however, made such slow progress that when I went to Paris thirty-five years after Murdoch's application of coal-gas for illuminating purposes, the Rue de Rivoli was, I believe, the only street lighted by its means. At the present day not less than seven millions of tons of coal are annually used in the public gas-works of the United Kingdom alone. During the process of distilling gas a considerable quantity of tarry substances comes over, and along with it a certain amount of watery matter. The former, known as coal-tar, for many years in my life was burnt or run away, and all the watery portion, containing the nitrogen in the form of ammonia, found its way also into the drains which led to the rivers. Chemistry afterwards opened out extensive fields for the utilisation of this liquid tarry hydrocarbon, and the ammonia for some years past has been converted into sulphate, and handed over to the husbandman as a source of nitrogen for his growing crops. If all the coal treated in our gasworks were made to yield its ammonia, more than 60,000 tons of the sulphate must be produced, worth, at less than half its former price, about £600,000 a year. To this sum has to be added the tar, of which I shall speak hereafter.

I suppose we are within the mark in saying that more than fifteen million tons of coal are annually coked for the use of our ironworks. The whole of this is effected in ovens where the gas is burnt under conditions which preclude the possibility of any tar or ammonia being rendered available. My firm were early adventurers in the field for avoiding this terrible waste in this country. The coal was placed in ovens, which were virtually retorts; the gas evolved during the process was passed through a series of condensers, which intercepted the tar and

ammoniacal solution, and the gaseous hydrocarbons, thus purified, were used for heating the ovens. Coke so made, however, was found less suitable for blast-furnace work than that obtained by direct application of heat to the surface of the coal, and the plan, to our disappointment and regret, was abandoned. Thus an annual loss of sulphate of ammonia is incurred worth considerably above a million sterling. From both these sources of ammonia—gasworks and occasionally coke-ovens—9000 to 10,000 cubic feet of gas per ton of coal is obtained, and a quantity of sulphate represented by something under 5 lb. of ammoniacal gas.

Of the pig-iron produced in Great Britain, about one million tons are obtained by the use of raw coal, of which about 2 tons are required per ton of metal, capable of furnishing about 17,000 tons annually of sulphate of ammonia. The success which had attended the extraction of ammonia from the gas made for illuminating purposes led the Scotch ironmasters to consider the feasibility of applying condensers to the gases as they leave their blast-furnaces. In the blast-furnace, however, not only are the 10,000 cubic feet of hydrocarbons to be gasified, but all the fixed carbon, save the small quantity which enters into combination with the iron, escapes as carbonic oxide or carbonic acid. In addition to this, we have the carbonic acid of the flux, and the nitrogen of the blast, which more than doubles the volume of the gases, so that the ammoniacal gas rarely exceeds $\frac{1}{800}$ of the total, and is generally considerably less even than this. The lowest consumption of raw bituminous coal per ton of iron made, I have ever heard of, is a trifle above 31 cwt., but it often exceeds the 40 cwts. named. According to analysis, the blast-furnace gases using the lesser weight of fuel had the following composition:—

	Volumetric.	By weight.
Carbonic acid . . .	8.61	18.08 = 3.56 C.
Carbonic oxide . . .	28.06	27.12 = 11.62
Marsh-gas . . .	4.37	2.41 = 0.96
Hydrogen . . .	5.45	0.38
Ammonia . . .	0.13	0.08 16.14
Nitrogen . . .	53.38	51.69
Water . . .	—	5.34
Total . . .	100.00	Total 100.00

Thus one volume of ammonia was accompanied by 769 volumes, or 1250 parts by weight, of other gases. It is estimated that each ton of coal burnt in the furnace is accompanied by the generation of about 90,000 cubic feet of gas, and that it yields 4.38 lb. of ammoniacal gas. Under such circumstances it is quite obvious that the condensation of so small a quantity of this gaseous alkali becomes a very difficult problem, as compared with operations where the same quantity has to be extracted from something like one-tenth of this enormous volume of gas.

Although Mr. Aitkin had called attention to the subject, Messrs. Baird & Co. were, I believe, the first to enter into this new field of research, and at an early period of their progress I was permitted, by this historical house in the Scotch iron trade, to examine the stupendous apparatus they had erected at Gartsherrie for preventing the loss of the valuable alkaline gas, which up to that time had been wasted. The example of Messrs. Baird has been followed by other firms, so that at the present moment almost every furnace in Scotland now in work is provided with the necessary appliances for the recovery of ammonia and its conversion into sulphate. Among the latest of these adventurers are my other friends Messrs. Merry & Cuninghame, by whom, and by the constructors of their plant, I have been supplied with the fullest particulars of the process as it is followed at the Carnbroe Works.

We will now proceed to examine the nature of the establishment by which this remarkable result is obtained, effected as it is with almost the completeness of a laboratory experiment, in apparatus designed and erected by Messrs. R. & J. Dempster. The plant used in the Dempster mode of obtaining products from the blast-furnace gases at Carnbroe consists primarily of dust-boxes, condensers, exhausters, washers, scrubbers, and separators, along with the tar and ammonia plants for working up the recovered tar and the so-called ammoniacal liquor. The gas is taken from the furnaces into the main gas-tube in ordinary use from close-topped furnaces; it then enters the dust-boxes, where the dust, carried over in suspension or vapourised with the gases, is intercepted with some 80 per cent. of the associated tar. The dust is deposited in the first or inlet partition, and is run out with the tar into a small settling tank, where the sedi-

ment is lodged, the tar being allowed to run into the store-tank along with that portion recovered in the other sections of the dust-box. The gas, on leaving the dust-boxes, enters the condensers, which, like all the other parts of the gas-plant, are in duplicate, and are arranged with valves, so that, in case of any part getting out of order, it can be shut off without interfering with the other portions of the apparatus. Each set of condensers consists of 144 wrought-iron tubes, 20 inches internal diameter by 55 feet high, the whole being supported on cast-iron boxes, which are arranged with partitions for giving the gas the full travel of the condensers. The total length of piping thus in use is about three miles, having an external area of about 48,000 superficial feet. The condensed tar and ammoniacal liquor are taken off by trapped overflows, and conveyed from these into a separator, and thence into the respective tar and liquor store-tanks. The temperature of the gas on entering the condensers averaged 130° Fahr., and on leaving 60° Fahr. This may appear very cool to those who are accustomed to the use of furnaces fed with coke instead of raw coals, the greater reduction of temperature being of course due to the absorption of heat in gasifying the volatile portions of the raw coal. The tubes, it should be stated, are cooled externally by an arrangement of water-sprays fixed near their upper extremities.

After leaving the condensers the gas passes through the exhausters, which are of the reciprocating type, and are so arranged that the gas-cylinders and all the gas-connections are placed outside the exhauster-house, in order to avoid risks in case of leaky connections. Thus all danger arising from the explosion of any accumulation of gas in the engine-house itself is avoided. Each exhauster is composed of two steam-cylinders and four gas-cylinders, and is capable of passing 550 cubic feet of gas per revolution. The design of the exhausters is such as to draw off the gas in a very steady manner, the pistons working at one-quarter centre. The engines are regulated by gas-governors, worked by the pressure of gas in the main gas-tube. The gas is next forced into the washers, which consist of four cast-iron boxes sealed with the ammoniacal liquor itself. The gas enters in the centre of each washer, and after being washed

by meeting the water-spray caused by the gas being broken up by perforated plates, reaches the outlets, which are on each side of the washers. The washers are sealed with the liquor that comes from the scrubbers, which constitutes the next element of the apparatus, and the overflow liquor or seal of the washers is regulated by patent slide-valves. The overflow liquor from the washers is carried to a separator which works exactly opposite to the separator for dividing the tar and liquor from the condenser-boxes, the tar being of less specific gravity than the liquor. After leaving the separator, the tar and liquor flow to their respective store-tanks. The gas, after quitting the washers, then passes forward into the scrubbers, which consist of three towers, each 120 feet by 18 feet in diameter. These towers are filled with thin boards, about 7 inches wide, set on edge, each tier of boards being at right angles to those adjoining it. The gas enters No. 1 scrubber at the bottom, and in travelling to the outlet at its top meets the liquor which is pumped from the tank to the so-called distributor, which revolves in the inside of the top of the scrubber, causing the whole area of scrubber to be equally wetted, and thus presenting a very large scrubbing surface for the gas to travel over. The gas then leaves No. 1 scrubber and is conveyed to the bottom of No. 2 scrubber, where it undergoes a similar treatment as in No. 1, and then passes on to No. 3 scrubber, which is also filled with boards still more closely packed than Nos. 1 and 2, and in this tower fresh clean water is used, for arresting the last traces of ammonia.

Suitable water-valves are attached to each scrubber to enable the gas to be shut off from any of the lot, and to allow the others to be kept at work. The scrubbers are also provided with relief-valves, and, as in other parts of the plant, there are suitable manholes for cleaning, &c. The washed gas, thus deprived of its ammonia, is then conveyed to the hot-air stoves and boilers at the ironworks, and used in the ordinary way as fuel. The yield of raw products has averaged 120 gallons of ammoniacal liquor, of 2 degrees of Twaddell's hydrometer, and 25 gallons of tar, per ton of coal used in the furnaces.

The ammoniacal gas is driven off from the liquor by means of steam in continuous ammonia-stills, lime being introduced

into the bottom compartment of the stills to remove any fixed ammonia, should this be present in sufficient quantity to pay for recovery. The steam required is obtained by blast-furnace gas which has passed through the condensing apparatus. The ammoniacal gas from the stills is then passed into saturators containing sulphuric acid, where the sulphate of ammonia is deposited, which is then placed on draining tables, and afterwards transferred to the sulphate store-house. The tar is treated in eight vertical tar-stills, each of which is capable of holding 7000 gallons. The stills are furnished with condensing worms and tanks, and oil-receivers. The oil is taken from the receivers into the store-boilers, and then blown by compressed air into store-tanks. The pitch left in the stills at the end of each distillation is run out into the pitch cooler on leaving the stills, and is then put into receptacles for storing it. Inasmuch as a portion, probably a considerable portion, of the tar is distilled at a much lower temperature in the blast-furnace than when the operation is conducted in a gas-retort or in a coke-oven adapted for the purpose, we may be prepared to hear that the products differ in their properties from those obtained in the production of illuminating gas or coke. Accordingly, it has been found that the tar is unsuitable for the production of aniline, or other tar colours. It has, however, been ascertained that by passing the blast-furnace tar over red-hot coke, benzol and anthracene have been obtained. It is therefore not unlikely that future researches may confer a higher value on that substance than it now possesses.

By the courtesy of the Carnbroe Chemical Company, I am enabled to place before the meeting the results obtained at Messrs. Merry & Cuninghame's ironworks over a period of three weeks. In this time three of their furnaces were being blown during a fortnight, and four during the third week, equal, therefore, to three and one-third furnaces for the whole time. The weight of coal consumed was 5841 tons, which gave the following quantities of the three products :—

	Tons	Cwt.				
Sulphate of ammonia	48	8	sold at £10 10s. =	£508	4	0
Pitch	361	0	" 21s. =	379	1	0
Oil	33,750	gallons	1½d. =	210	18	9
				£1,098	3	9
Paid :—Wages, sulphuric acid, management, railway						
dues, and allowance for depreciation of plant . .				379	12	3
Balance, Profit and				£718	11	6
Interest on plant = 2s. 5½d. per ton of coal.						

If, as is proper, we regard the addition of sulphate of ammonia hitherto wasted, in a national point of view, we are entitled to credit the processes by which this is achieved with the difference between its present and its former price. This, upon the quantity dealt with in the statement of account just rendered, means a gain of about £250.

The propriety has been suggested of using coal generally in the form of gas, obtained by preliminary treatment in a Siemens producer. By such a mode of procedure the ammonia capable of being afforded by bituminous coal could be collected. To effect this, however, the gases would have to be cooled down in the manner described, which would involve a sacrifice of about 30 per cent. of the heating power of the fuel used. With cheap coal and a higher price for the ammonia salt, there does not appear any reason to doubt the practicability of such a system, but as matters now stand its advantages as a lucrative undertaking, in many cases, appear to be doubtful.

Two hundred and twenty-three years ago, Brandt, a Hamburg alchemist, while engaged in searching for a body capable of converting silver into gold, discovered phosphorus. After the lapse of two hundred years this element has had an indifferent reputation among iron-makers, owing to its tendency, in their experience, to reverse the order of the transmutation in the two metals to which Brandt hoped to apply it. Low, however, as phosphorus stood in the estimation of the ironmaster, something like 3 to 4 lb. are indispensable for building up and maintaining the life of every full-grown human being. Although of very frequent, we may even say of universal, occurrence in the crust of the earth, when compared with the enormous masses of silicious, aluminous, and calcic minerals, which abound everywhere, phosphorus cannot be otherwise regarded than as an

extremely rare substance. It is, moreover, held firmly united, as phosphoric acid, with certain earths, of which lime is probably the chief. From the minerals which contain phosphorus it is transferred by the disintegration of its matrix to the alluvial deposits, in which, however, as soil it exists in very minute quantities.

In following what may be regarded as the concentration of a substance so sparingly distributed as that in question, let us imagine a period in the earth's history when the uppermost of the sedimentary but non-fossiliferous rocks constituted the uppermost series of the surface of the globe. By very slow degrees, by chemical action, in which atmospheric carbonic acid probably played an important rôle, minute traces of phosphoric acid as earthy phosphates were possibly transferred to the alluvial deposits which overlaid the actual rock. Upon this a low type of plants—how created we know not—established itself. By the decay of this vegetable covering, carbonic and organic acids were generated, which would tend to accelerate the assimilation of earthy phosphate, and thus prepare the soil for growing a higher order of plants. Ultimately a vegetation richer again in phosphoric acid would take the place of less perfect forms, and by an increase in nitrogen, derived from atmospheric ammonia, suitable food for supporting a low order of animal life was brought into existence. By a continuance of this evolution, the surface of the earth became endowed with the power of sustaining life as we know it to exist in the highest orders of animated beings. At the same time fresh sedimentary rocks were covering up the earlier-formed non-fossiliferous strata. It seems not improbable that, while these geological changes were in progress, chemical action resembling that which led to an accumulation of phosphoric acid appears to have been concerned in the concentration and localisation of oxide of iron, which probably gave rise to the deposits of iron-ores as we find them at the present day.

For convenience of future reference, I may remind you of the order of gradual development of organic life as the same is indicated by the remains of plants and animals in the strata forming the crust of our earth. These are grouped in eight divisions in the following list, beginning at the lowest in the series :—1. Sedimentary pre-Silurian rocks, destitute of any sign

of organic life. 2. Sedimentary pre-Silurian rocks, containing vegetable remains. 3. Silurian rocks, first appearance of invertebrates. 4. Devonian formation, containing fish. 5. Carboniferous age, rich in vegetable and animal remains. 6. Rocks of the Triassic, Jurassic, and Cretaceous periods constituting the Reptilian age. 7. The Tertiary or Mammalian age. 8. The age of man, of whom practically no fossil remains are found.

I presume that questions of temperature, and therefore of climate, may have delayed the appearance of the human race on the face of our globe. On the other hand, possibly the quantity of readily-available phosphorus required for the higher organisation of man may have been a factor in determining the period of his taking his place among what is generally known as creation. I am induced to offer this remark because the age and composition of our ores of iron seem to constitute a key to the gradual increase of phosphorus in the later periods of the earth's transformations. It is, I believe, generally supposed that carbonic or other acids, by their known action on oxide of iron, have been the means of gathering up, as it were, the sparingly-disseminated quantities of this metal found in the soil. Such an opinion is probably founded on the fact that this is a process which is in operation at the present day. Iron is known to be so dissolved, but on coming under atmospheric influence, the metal is peroxidised and carried forward into lakes, where it is collected in certain localities in Sweden, and used as an ore in the blast-furnaces of that country. We have, also, accumulations of oxide of iron, known as bog iron-ore, which have unquestionably been formed by the agency just referred to. Besides this proof of the agency of carbonic acid in concentrating iron, we have the fact that carbonate of iron is a frequent state of combination in which the metal is found in its ore, and when it, by the agency of the atmosphere, has been converted into oxide, nuclei of unchanged carbonate are of frequent occurrence.

There are to be found in different localities—Eisenerz, in Styria, being one of the most remarkable—deposits of spathose iron-ore, so called from its crystallised or semi-crystallised structure. This is carbonate of iron, containing but small quantities of earthy admixture. Its colour is pure white when it has not been affected by exposure to the air; at other times

it is highly coloured from having been changed to peroxide, with loss of more or less of its carbonic acid. The following analyses, taken from the work of our former president, Dr. Percy, exhibit the nature of this change:—

Protoxide of iron . . .	43·84	49·47	49·77	10·77	...
Sesquioxide of iron . . .	0·82	...	0·81	49·57	73·08
Protoxide of manganese . . .	12·64	2·42	1·93	3·06	6·60
Earthy matter, &c. . . .	3·66	10·40	9·99	13·66	7·57
Carbonic acid	38·86	37·71	37·20	14·49	0·13
Phosphoric acid . . . . .	...	Trace	Trace	0·01	0·22
Water	0·18	...	0·30	8·44	12·40
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
	100·00	100·00	100·00	100·00	100·00

Whether the minute quantities of phosphoric acid present in these specimens were due to the absence of this body in the strata, or to the inability of carbonic acid, under the circumstances which obtained at the period when the iron was dissolving, to carry away phosphate, it would be difficult to say. One thing, however, seems pretty clearly established—viz., that the ores of iron found so abundantly in the older rocks are, compared with those of more recent origin, singularly deficient in phosphoric compounds. The Labour Commissioner of the United States gives certain particulars respecting some 100 specimens of ore. Of these, thirty-five average 65·43 per cent. of metallic iron, which, if all were peroxidised, leaves only 6·53 per cent. of foreign matter. If all these were the produce of the Lake Superior mines—and most of them doubtless are so—we may, from the hardness of the older rocks in which they occur, expect only a small admixture of earthy contamination. These ores, therefore, belong to strata of the Silurian age, a period when phosphoric acid had not become concentrated to the extent in which it is found in more recent geological horizons. Accordingly, we have only 0·061 per cent. of phosphorus in these thirty-five cases. The next group of ten varieties of ore gives an average of 57·8 per cent. of iron, and therefore 17·43 per cent. of earths, and 0·222 of phosphorus. We then come to twenty-six specimens of much more recent origin, and containing only 45·61 per cent. of iron, 34·15 of earths, and 0·339 per cent. of phosphoric acid. Lastly, there are seven examples, chiefly of the coal formation, with 35·46 of iron, 35·46 of earths (49·37 inclusive of carbonic acid) and 0·474 per cent. of phosphoric acid.

In order to extend the field of observation, I have taken out of a list of analyses, also in Percy's work on iron and steel, the following English examples, which I have placed according to their geological sequence, beginning with the oldest.

Quality of the Ore.	Geological Position.	Number of Examples.	Average. Phosphoric Acid.	Average. Iron.
			Per Cent.	Per Cent.
Red hæmatite . .	Probably mountain limestone	Six	Trace	64·89
South Wales . .	Coal formation	Ten	0·151	28·42
West Yorkshire . .	Coal formation	Six	0·139	32·08
South Staffordshire .	Coal formation, ordinary run	Ten	0·201	37·82
Derbyshire . .	Coal formation	Nine	0·204	29·15
Most likely North Yorkshire . .	Lias	Three	0·542	38·95

In thus tabulating the ores of iron to show a possibility of their content of phosphorus having increased as the concentration of this element by vegetation progressed, I would not be understood as maintaining that there are not exceptions to such a supposed law. On the contrary, I am fully aware that exceptions are to be found to its operations, one, indeed, appearing in the table of examples just inserted. In it, among British ores at the head of the list, in comparative freedom from phosphorus, stands red hematite, found so abundantly in a formation so recent as the carboniferous limestone, and in the adjoining rocks. It would, indeed, have been remarkable if, during the extraordinary convulsions which accompanied the changes in the course of the transition of our planet from a probable state of vapour to that of the solid rocks as we now find it, there had not been many exceptions to any particular sequence of events.

I have hitherto only spoken of the implied presence of water as the agent in the deposition of the sedimentary rocks. If, however, it were suggested that all the various constituents forming the crust of the earth existed at any particular time in a state of fusion, they would have constituted a homogeneous mass, somewhat resembling basaltic rock in appearance and composition. Under such circumstances, it would be difficult to conceive how any one of them could be found, as is the case, almost chemically

free from any foreign admixture. As an example, I have known quartzite to consist of 99·75 of silica, and some of our mountains of limestone are nearly pure carbonate of lime.

If at any time the temperature of the solidifying mass of the globe resembled that of the sun, there is reason for believing that the elements composing our earth would have existed in an uncombined condition. In time, as they lost heat, combination would take place, and that in the order of the elevation of the temperature required for their dissociation, the remainder being still kept apart. In this way there might, in certain localities, be large accumulations of silica; in others of lime, alumina, or magnesia; while in others, again, a mixture of two or more might be effected. Along with these, at different periods, there might be disseminated or not, the minerals of rarer occurrence, such as the metals or their compounds, phosphorus, sulphur, &c. Upon these, water formed from its vapour would descend, and, occasionally, one or other of the four preponderating earths might be deposited, as we now find them, in a state of almost absolute purity.

There is another alternative. Our blast-furnaces, I conceive, are actually capable of subliming earthy matter, because I find that the white smoke which escapes from the throat differs essentially in composition from the minerals which enter the furnace. By this I mean that the difference consists in the relation which the component parts bear to each other in point of quantity. I infer, therefore, that the vapourising points, as might be looked for, differ considerably in the temperature at which they take place, and these differences might regulate the order of the separation and deposition of the various bodies as they now exist.

By the time we arrive at the period when the coal-bearing strata were deposited, it will be remembered that this was concurrent with a great increase in the quantity of vegetable and animal remains in the rocks of that age. If, then, the chemical action which influenced the solution of iron by carbonic and vegetable acids, effected at the same time the separation of the phosphates, we must be prepared for expecting an increase of phosphoric acid in the iron-ore. From whatever cause, it is quite certain that the clay ironstones of the Carboniferous strata

are so charged with phosphoric acid that the pig-iron they produce is entirely unfitted for the ordinary Bessemer process. It is only, however, when we meet with iron-ore in the still more recently deposited rocks of the Lias formation, that we meet with the full measure of inconvenience caused by the presence of phosphorus. The iron-mud so produced and accompanied by earthy mud, the result of the disintegration of the shales of the period, would be carried down into the seas of that time. There the accumulated remains of organised beings of marine origin, which had derived some phosphorus from the sea they inhabited, were buried in the mud containing carbonate of iron, and so became part and parcel of the ironstone now so extensively worked in the Cleveland Hills. Among the animals so entombed some were of considerable dimensions, and one of these having been met with in one of the mines belonging to my firm, at the time I was engaged in preparing this paper, I have brought two or three joints of its vertebral column for your inspection. The skeleton was, unfortunately, destroyed by the explosion which separated it from the ironstone containing it. Enough, however, was obtained to show that it had belonged to an animal, we think an ichthyosaurus, having a length of somewhere near 14 feet.

In order to convey an idea of the volumetric extent to which the metalloids enter into Cleveland pig iron, I constructed a diagram showing the relations they bear to the metal itself. In it, the pure metal iron is represented by an equal-sided rectangular figure containing 400 square inches, being then a square of 20 inches. With this as a standard of comparison, the squares representing the other substances would have the following dimensions on a side :—Carbon, 7·058 inches ; phosphorus, 4·70 inches ; silicon, 4·680 inches ; sulphur, 1·54 inches. Instead, however, of forming a square of $22\frac{1}{2}$ inches, as it would have done had there been no change in the average specific gravity, it constitutes a figure of 21 inches on a side. Rich, comparatively speaking, as Cleveland ironstone is in phosphoric acid, it is obvious, although a low-priced mineral, that it would be impracticable to use it as a fertiliser of our land. When, however, we submit it to the action of the blast-furnace the phosphorus contained in $3\frac{1}{4}$ tons of ore passes into 20 cwt. of pig-iron. A good deal more than

twenty years ago I pointed out the loss our country was incurring by allowing the phosphorus of 20,000 tons of phosphoric acid to poison 2,000,000 tons of pig-iron annually, at the same time that our ships were scouring the seas in search of that identical substance from the remotest parts of the earth.

We are, I am glad to say, on the way of eventually removing this scandal from the manufacturing escutcheon of the nation, by the introduction of the basic process. Attempts, soon after its discovery, were made in Germany to free the slag into which the phosphorus as phosphoric acid passes from what was useless as a manure, but which slag contains ten times as much phosphoric acid as did the parent ironstone. It was, however, speedily discovered that in the laboratory of Nature this operation was performed by the plants requiring phosphoric acid, not with the same speed, but much more cheaply than it could be done in the workshops of the chemist.

DISCUSSION.

Sir LOWTHIAN BELL regretted that, owing to his engagements in connection with the American volume, he had been unable to complete the present paper in time to have it laid before the meeting in its printed form.

The PRESIDENT said he was sure that the members were greatly indebted to Sir Lowthian Bell for his extremely interesting account of the recovery of important by-products attending the production of iron and its conversion into steel. The paper perhaps did not afford much material for discussion, but they should be glad to hear any observations upon it, especially with reference to the important information it contained as to the apparatus now at work on a large scale for the recovery of ammonia, tar, and oil from the products of the blast furnace. They had already had in former communications some account of the elimination of phosphorus from iron, its passage into the slag in the basic process, and the utilisation of this slag as manure; but in Sir Lowthian Bell's paper the subject would be found dealt with in a more complete form. Those results were extremely interesting and important. The apparatus, of which drawings were exhibited, evidently utilised in a very complete manner the principles which had already been applied to the purification of coal-gas, the difference in that case and the present one being that in coal-gas manufacture the main object was to remove the least traces of ammonia and other impurities, with a view to having the gas as pure as possible; whereas in the present case the primary object was to remove the products from the blast furnace gases as completely as possible, with a view to their utilisation.

Mr. G. J. SNELUS said that the few words which he desired to say on the paper had more reference to agriculture than to the manufacture of iron. It so happened that within the last twelve months he had been experimenting upon the use of sulphate of ammonia in regard to the growth of grass; and he thought that a simple statement of what he had noticed

might be useful to some of the members, and would help to show the advantage of sulphate, although, of course, agriculturists already well knew the value of that manure. He had been experimenting with sulphate of ammonia in combination with nitrate of soda. He had applied about 1 cwt. of sulphate of ammonia, and 3 cwt. of nitrate of soda, per acre to grass on a lawn, and he had been remarkably struck with the enormously rapid growth of the grass under such circumstances. Within a week of the application of the mixture, the grass had begun to show a very vivid green, and within three weeks the blades of grass had lengthened four inches, thus showing the valuable effect of those constituents upon the growth of plants. He now understood that it had become perfectly practical to apply the same manure to fruit trees, and the cheapening of those commodities would be a very great advantage to the country generally. He thought that great credit was due to the gentlemen who had spent so much time and money in endeavouring to utilise those by-products. They were also indebted to Sir Lowthian Bell for having, notwithstanding the many other duties that he had to attend to, brought the matter before them in his interesting paper.

SIR LOWTHIAN BELL asked how the grass grew that had no sulphate of ammonia applied to it?

MR. SNELUS said that it made very little progress; it seemed simply to stand still. In his first experiment, he sowed the sulphate of ammonia and the nitrate of soda over half the lawn. He was doubtful whether he might not kill the grass, but the remarkable effect was produced of one half the lawn becoming a vivid green within a week, the other half being quite brown. He then applied the manure to the second half, and within another week the whole was as green as possible. He applied the mixture three times, at the rate of about 4 cwt. per acre, and it was astonishing to see the rapid effect that was produced.

SIR LOWTHIAN BELL asked if the experiment paid?

MR. SNELUS said that that was another thing. In his case it had paid very well.

Mr. CUNINGHAME said he had been very pleased with the description given of the apparatus. It might be taken as perfect in every detail. In regard to the question of profits, the statement of Sir Lowthian Bell was perfectly correct at the time the paper was written; but, like other commodities, the by-products had their ups and downs, and at the present moment they were, like many other things in which they were interested, on the down line. On the question of profit and loss the results would not be always as Sir Lowthian Bell had stated, but must depend upon the fluctuations of the market. He might add that it was generally believed in the North that the fertiliser of the future would be basic phosphate and sulphate of ammonia, the latter for its stimulating and the former for its sustaining qualities; so that they might expect in future that the by-products of the blast furnace would play an important part in the agriculture of the country.

The PRESIDENT proposed a hearty vote of thanks to Sir Lowthian Bell, which was carried by acclamation.

CORRESPONDENCE.

Mr. HENRY SIMON, who has erected a number of coke-oven plants in England and on the Continent, sends the following notes about the experience of one such plant erected at Bilbao, which has been at work for a considerable period.

Every pound of coke manufactured in that establishment is used in blast furnaces, whereas in England the coke made in the ovens erected by Mr. Simon, at such collieries as Bearpark, or those of Messrs. Pease & Partners, although made from the same coal as that used at Bilbao, viz., the best Durham, is mostly used for foundry purposes—the prejudice against the use of an even excellent coke, if not presenting the silvery surface to which the trade has been accustomed from the Beehive coke, being as yet too strong in England.

Mr. Simon thinks that the following data may therefore be of interest, especially as all the coke produced at the Viscaya works in Bilbao is made from Durham coal imported into Spain for the purpose.

At Bilbao there are 140 Simon-Carvès coke ovens with recovery plant complete, and the Société "La Viscaya" is working three blast furnaces in conjunction with these ovens, the latter carbonising 2600–2700 tons of Durham coal per week, giving 1900 to 2000 tons of good hard coke. Each furnace is 66 feet high, one being 17 feet 8 inches in the bosh, and the other two 19 feet 8 inches in the bosh. The furnace mouth is 13 feet 7 inches diameter, and at the level of the tuyeres the diameter is 9 feet. The wind pressure is from 10 to 10½ inches mercury, and its temperature is about 740° C. for two of the furnaces, and about 900° C. for the other, which is fitted up with better heating stoves.

The coke, as above mentioned, is made from Durham coal (imported from Cornsey, Weardale, &c.), containing from 7 to 8 per cent. of ash and about 0·5 per cent. of sulphur.

All qualities of pig, from No. 1 up to Nos. 5 and 6, are made at the Viscaya works, according to the requirements of the steel-works there.

The average daily production of each furnace when making No. 1 pig iron is 105 to 110 tons; but when making this brand, and if the furnaces are in good order, they do make as much as 115 to 120 tons of pig daily.

The average daily production when making No. 4 and No. 5 iron is 125 to 130 tons for each furnace; but if the furnaces are in good order, they do make as much as 140, or even 150 tons of pig iron daily.

When making No. 1 pig, or extra-silicious No. 1 iron, the consumption of dry coke, deduction being made for moisture in the coke, is 1030 to 1040 kilos per ton of iron; when making No. 2 or No. 3 iron, the consumption is 1020 kilos, and when making No. 5 and 6 white iron, the consumption is 900 to 980 kilos.

Analyses of the pig iron made at the Viscaya works show the following results:—

No. 1 pig iron contains—

	Per Cent.
Silicon	from 2·20 to 2·30, and up to 3
Sulphur	0·015
Phosphor	0·03
Manganese	0·900
Combined carbon	0·30 to 0·50
Graphite	3·50 to 4

Nos. 5 and 6 pig iron contain—

	Per Cent.
Silicon	0·70
Sulphur	0·05 to 0·15
Phosphor	0·03
Manganese	0·7
Combined carbon	2½ to 3
Graphite	0·5

The iron with 0·05 per cent. of sulphur is a special iron used for Martin steel basic process.

The No. 1 iron made by the Viscaya Company is always in great demand.

ON AN
APPLIANCE FOR AUTOGRAPHICALLY RECORDING
THE TEMPERATURE OF FURNACES.

BY PROFESSOR ROBERTS-AUSTEN, C.B., F.R.S.

IN these days of accurate observation, when the speed of projectiles is both autographically recorded and their actual paths photographed, it is remarkable that the measurement of high temperatures has not kept pace with the recent industrial applications of physical methods. In the case of certain chemical and metallurgical processes, a variation of only a few degrees may, at certain stages of the operations, be fatal to their success, and even when heat is generated in the vast interior of a modern blast-furnace, the accurate regulation of the temperature is of great moment. The importance, for instance, of ascertaining by actual measurement the relation between the number of calories brought in by the blast and the total heat engendered by the combustion of fuel in the furnace, will be evident when the appropriation of the heat of an 80-foot blast furnace during the production of 20 cwts. of pig iron from Cleveland ore is considered. Of the total 93,000 calories which are employed, nearly 12,000 calories are brought in by the hot blast, or more than double the number allotted to the reduction of the calcium, silicon, phosphorus, sulphur, and elements other than iron present in the charge. The influence of the temperature of the blast is, moreover, as is well known, of great importance in determining the composition, and consequently the reductive energy of the gases formed at the level of the tuyers. Hence the need for accurately adjusting the temperature of the blast, if the furnace is to yield its maximum out-turn, or if the production of a given quality of iron is to be maintained. Analysis shows the degree of purity of the mass, for the application of chemistry to the metallurgy of iron has enabled amounts of foreign elements in iron to be estimated in the routine of daily work, even though not more than one hundredth part be present. May it not be hoped that, by giving increased attention to physical methods, it will be possible to regulate the thermal conditions which determine the passage of elements into the iron?

1892.—ii.

The adoption of thermo-junctions for the measurement of high temperatures has been for some years advocated by the author and will probably become widespread, Sir Lowthian Bell leading the way in this country by the introduction of platinum platinum-rhodium thermo-junctions into the hot-blast mains at the Clarence Works, the thermo-junctions being connected with a central laboratory where the indications they afford are translated into degrees by the aid of a suitable galvanometer scale.

Various other methods have, as is well known, been employed for measuring the temperature of the blast, but as yet a systematic method of obtaining autographic records of the temperatures has been wanting, and it would appear that the time has fully come for taking a step in advance. It was with much pleasure, therefore, that the author received a request from Mr. E. P. Martin, of Dowlais, that these Works might be furnished with an appliance which should faithfully record the temperature of the hot-blast stoves. Mr. Martin had already introduced at the new works at Cardiff a method for recording the periods at which the reversal of the valves was effected, and he was thoroughly able to appreciate the need for obtaining an equally trustworthy record as to the temperature attained. The present paper is the result of an effort to provide such an appliance by simplifying a piece of apparatus, already described by the author to the members of this Institute,* so as to render it serviceable for use in works.

The original apparatus consisted of a camera containing a reflecting galvanometer of the Depretz and D'Arsonval type, of about 200 ohms resistance. The thermo-junction, which is, of course, external to the camera, is connected with this galvanometer, and the amplitude of the deflection of a spot of light from the mirror affords the basis in calculating the temperature to which the thermo-junction has been raised. An autographic record of the temperature may then be readily obtained if the spot of light from the mirror falls into a sensitised photographic plate actuated by an astronomical clock or by other suitable mechanism. Such an appliance, though it has proved to be well adapted for conducting investigations, is not sufficiently simple for industrial purposes, and in order to render it generally useful it appeared that the following points had to be attended to:—

* *Journal*, No. i., 1891, p. 90.

1st. It was necessary to simplify the portion of the apparatus which receives and records the movement of the spot of light; and

2nd. To avoid the necessity for shifting a single thermo-junction from furnace to furnace by placing separate thermo-junctions in each furnace, provision being made for placing each centre of heat in turn, in connection with a single galvanometer and recording instrument.

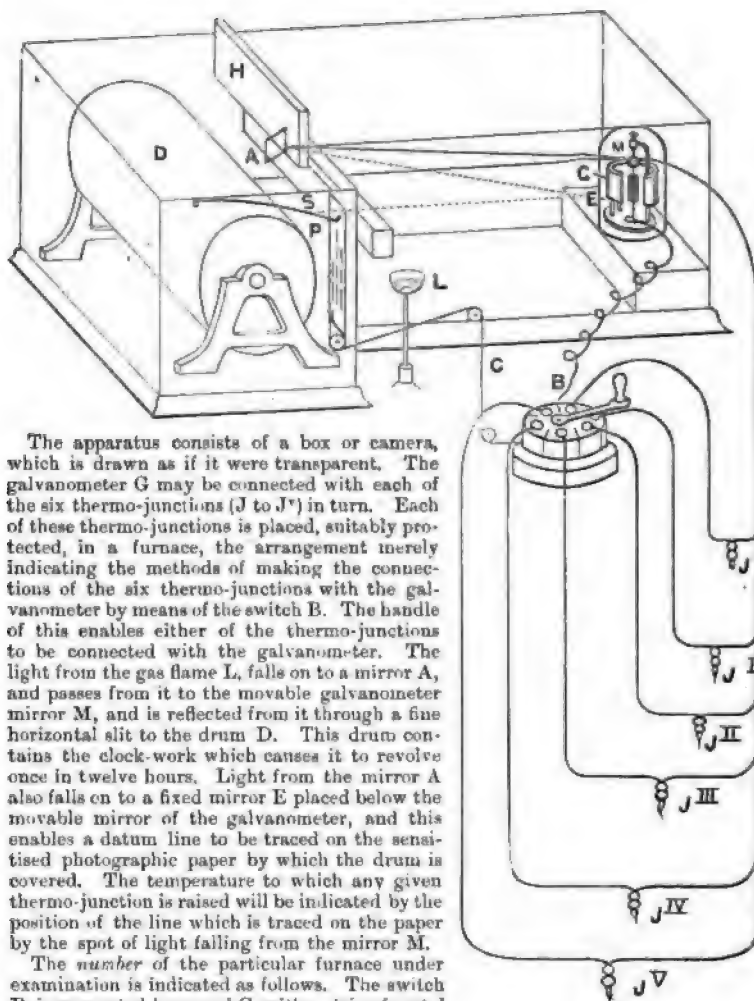
The first object has been attained by replacing the moving plate of the original apparatus by a brass cylinder, six inches in diameter, moved, at the rate of a single revolution in twelve hours, by clockwork contained within it. This cylinder has sensitised paper fixed round it, and the portion of the camera which contains it can be detached from the rest of the appliance and removed to the dark room for the development of the record imparted to the paper.

In the apparatus now submitted to the members of the Institute, provision is made for placing any one of six centres of heat, such as hot-blast stoves or furnaces, in connection with the galvanometer, and for obtaining within the period of the revolution of the cylinder a record of the temperature of any one or of all the six sources of heat. The record of a number of furnaces would, however, be intermittent, the duration of the test in any particular case being subject to the will of the operator, who, by merely turning a handle, determines which particular furnace shall be placed in connection with the galvanometer, and the length of time which shall be devoted to its test. This shifting of the electrical contact from furnace to furnace could readily be effected by clockwork, and the tests would then be entirely independent of manual adjustment.

The drawing (p. 36) shows the method adopted for indicating which particular source of heat is in connection with the galvanometer. If, for instance, No. 1 furnace is under examination, light from the lamp L passes through a single slit, and traces a single continuous datum line. The line traced by the light from the galvanometer mirror M, is more or less removed from this datum, and the position of any given point depends on the temperature to which the thermo-junction is raised at the moment the point is photographed. In the case of, say, No. 4 furnace, the datum line would be produced by allowing the light to fall through four fine slits, and a quadruple series of fine parallel lines would be produced, only one of the series being the true datum.

The photographic curves, which can readily be obtained, will,

it is hoped, render good service in connection with the metallurgy of iron and steel.



The apparatus consists of a box or camera, which is drawn as if it were transparent. The galvanometer G may be connected with each of the six thermo-junctions (J to JV) in turn. Each of these thermo-junctions is placed, suitably protected, in a furnace, the arrangement merely indicating the methods of making the connections of the six thermo-junctions with the galvanometer by means of the switch B. The handle of this enables either of the thermo-junctions to be connected with the galvanometer. The light from the gas flame L, falls on to a mirror A, and passes from it to the movable galvanometer mirror M, and is reflected from it through a fine horizontal slit to the drum D. This drum contains the clock-work which causes it to revolve once in twelve hours. Light from the mirror A also falls on to a fixed mirror E placed below the movable mirror of the galvanometer, and this enables a datum line to be traced on the sensitised photographic paper by which the drum is covered. The temperature to which any given thermo-junction is raised will be indicated by the position of the line which is traced on the paper by the spot of light falling from the mirror M.

The number of the particular furnace under examination is indicated as follows. The switch B, is connected by a cord C, with a strip of metal P, and this strip, which is supported by a spring S, bears a number of fine horizontal slits. If, for instance, No. 3 furnace is under examination, light from the lamp L will fall through a fine horizontal slit in the wall of the box containing the drum, and through three slits in the vertical strip P. A triple continuous datum line will be photographed on the drum as long as connection is maintained with No. 3 furnace. If No. 2 furnace is being tested, the datum line will be double, while if the furnace is No. 1, the line will be single.

A slide H, may be screwed down so as to exclude light from the portion of the camera which contains the drum. This portion may then be removed to the dark room, where the record as traced on the sensitised paper is developed.

DISCUSSION.

The PRESIDENT said it would be difficult to conceive a more simple, or apparently a more accurate, system of recording temperatures than that which Professor Roberts-Austen had applied, or a more practical form than that which he had given it for the purposes of the blast furnace manager. He was quite sure that in the hands of Mr. Martin it would receive extensive application and a thorough test, so that at a future meeting they would be able to cross-examine that gentleman as to the extent to which he was satisfied with Professor Roberts-Austen's apparatus. Dr. Anderson had had some experience of the working of the system of temperature record, and the members would be glad to know the opinion entertained by him regarding its merits.

Dr. ANDERSON, F.R.S., said that his experience had hitherto been confined to the experiments which Professor Roberts-Austen had been making for the Institution of Mechanical Engineers. The apparatus made for the Royal Arsenal at Woolwich had not yet been put into practical use, but it was impossible to overrate the importance of such an accurate method of measuring high temperatures. The more they studied the composition of steel, the more evident became the enormous importance of very small variations of temperature at the heats at which steel was worked, and the more evident became the desirability of depending upon something better than the eye or the judgment of the operative, especially when they had to deal with large masses and with varying lights. He had spoken about the Le Chatelier pyrometer to electrical experts, and nearly all of them had said that the apparatus was possibly a good thing, but that a thermo-couple was not at all permanent, and would alter its zero-point and the range of its readings very quickly. He should like to ask Professor Roberts-Austen if it was a fact that the durability was so small that in a few hours the character of the indications might be entirely altered.

Sir LOWTHIAN BELL said he could perhaps answer the ques-

tion with some degree of confidence from the experience they had had at the Clarence Works with the thermo-electric pyrometer. They had noticed nothing of the kind mentioned by Dr. Anderson. The indications of to-day were the same as those at the beginning of its application, and the same might be said regarding the junctions. He thought, therefore, that it might be safely inferred that there was no such change as had been apprehended by Dr. Anderson. At a previous meeting, when Professor Roberts-Austen's paper was read, a question had been put to him (Sir Lowthian Bell), by Mr. Charles Wood, of Middlesbrough, as to the durability of the junctions. He would not say that they did not wear out; but he did not think in the eleven furnaces at which they were working they had lost more than three or four, which, as the expense was so trifling, was a matter of no moment.

Mr. E. P. MARTIN said he wished to congratulate Professor Roberts-Austen on his complete and useful instrument for metallurgists, especially to those to whom the question of temperature was of great importance. He had no doubt that it would prove an absolutely perfect instrument. They had tried an indicator for working the hot blast stoves, which had proved of very great use in recording the times at which the stoves were changed. They had found by using the indicator that mistakes occurred more frequently than they had believed, especially at the change of turns. The night-stove man coming on, say, had believed that a certain stove had been changed, whereas it had not been changed, and the result was that a cold stove was used, and worked double its time, blowing a reduced temperature into the blast furnace, and probably occasioning great irregularities. The stove indicator checked the attendant, and any mistake could be pointed out. The apparatus described by Professor Roberts-Austen would, he thought, be still more useful. They would be able to ascertain whether the stove had been properly heated, or whether it was used too long, or was dirty, and by its assistance they would be able to keep the temperature of the blast within a few degrees of what they required it to be.

. Mr. PARKER inquired how the junction was fixed in the stoves

and what voltage was generated by the junction? It would also be satisfactory to those who were in the iron trade if they had a junction to look at.

The PRESIDENT said that a junction was shown at a former meeting.

Mr. PARKER said he should like to know what method of insulation was adopted?

Professor ROBERTS-AUSTEN said that had been previously described. With regard to the actual insertion of the pyrometer in the hot blast mains, Sir Lowthian Bell would be able to give information on that subject. He (Professor Roberts-Austen) was mainly interested in the recording part of the apparatus.

Sir LOWTHIAN BELL said that the junction was just placed in the main itself.

Mr. PARKER asked what was the form of the junction?

Sir LOWTHIAN BELL said the junction was what was seen in the instrument itself.

Professor ROBERTS-AUSTEN said that the junction was a piece of wire, about as thick as an ordinary pin. It was of platinum and rhodium, sometimes soldered by a tiny sphere of gold. The wires were usually merely twisted together; the junction might be covered with a layer of clay or not. Unless it was coming in contact with a shower of fine metallic rain, it was better to leave it free.

Sir LOWTHIAN BELL said that of course communication was made with the galvanometer, which was placed at the office, from every furnace. Every furnace had a wire ending at the office. There was a table containing the number of each furnace, and the attendant had merely to make contact by putting a plug into the aperture communicating with each furnace, when he saw at once what the temperature was.

Professor ROBERTS-AUSTEN said that the most suitable resistance of each galvanometer was about 200 ohms. With regard to the durability of the thermo-couple, he need hardly remind Dr. Anderson that there were thermo-couples and thermo-couples. The platinum-iridium one, adopted by Barus, and which afforded, it should not be forgotten, the basis upon which the trustworthiness of thermo-couples rested. Barus compared step by step the indications of the platinum-iridium thermo-couple, as taken side by side with an air thermometer, and proved that they ran absolutely together. The iridium-platinum junction, therefore, was an accurate one, and one which was more sensitive than the platinum, platinum-rhodium one. Physicists were apt to accuse metallurgists of employing a precarious instrument, mainly because the thermo-couples hitherto used had not been carefully chosen, and unsuitable metals had been employed. That the platinum-rhodium couple was a delicate one could be seen from the photographs he exhibited; it would take up the variations of heat with extreme rapidity, and it was also, according to his experience, extremely durable. He did not think it would vary after a month's continuous use by more than a very few degrees.

Mr. JEREMIAH HEAD asked if he was right in supposing that, for a permanent record of several furnaces, one complete apparatus was required at each?

Professor ROBERTS-AUSTEN said that a thermo-junction only was required for each furnace, as any one of a series of furnaces could be placed in turn in contact with one galvanometer in a central laboratory. One thermo-junction being applied to each furnace, conductors were led from it to the galvanometer. The nature of the switch used could be seen. It was a switch suited for six furnaces. Each arm of the switch was connected with a thermo-junction, and each junction could be placed in turn in connection with a single galvanometer. The result was that the record of the six furnaces would be intermittent, but the duration of the test in each particular case depended entirely on the will of the operator.

Mr. J. E. STEAD asked whether the switch was automatically kept moving round? It would appear from the description that if clockwork was used, the instrument would be an automatic recorder.

Professor ROBERTS-AUSTEN said that he had stated in the paper that the shifting of the *contact* of the galvanometer from furnace to furnace could be regulated by clockwork as well as by hand, and that then human intervention would entirely cease.

The PRESIDENT, in proposing a vote of thanks to the author, said he was glad to know that Professor Roberts-Austen had so far satisfied himself that the apparatus was a working one, and that he was about to hand it over to Mr. Martin, who would now be able to furnish a valuable opinion upon it.

THE LIVERPOOL OVERHEAD RAILWAY.

By JAMES HENRY GREATHEAD, M. Inst. C.E.

THE question of improved and more rapid means of transit for passengers is occupying attention in many of the great cities at the present time. With the extension of areas covered, the question becomes increasingly pressing.

In London it has been under consideration for many years, and during the last session a joint-committee of the two Houses of Parliament reported favourably upon a number of proposed underground electric railways of the type of the City & South London Railway, completed and opened for traffic in 1890.

In Paris, Berlin, and Vienna similar railways have been promoted and are under discussion. In New York, a city long since provided with elevated railways and tramways along most of the main thoroughfares, a Rapid Transit Commission has lately reported in favour of an extensive system of underground electric railways, and in other American cities, notwithstanding the rapid development of electrically worked tramways, additional facilities in the shape of over- and underground lines are being considered.

This question, then, is an important one for engineers and for the iron industries.

All the proposed underground lines are, since the construction of the City & South London Railway, proposed to be made of iron, and that material must necessarily enter largely into the construction of any overhead railway.

The particular railway under discussion is composed almost entirely of wrought iron. The line, now approaching completion, traverses the whole length of the famous Liverpool docks, a distance of about six miles (as will be seen by reference to the diagrams). The extensions north and south, authorised last session, are also shown, and it will be seen that they go beyond the docks and away from the river in order to give better access between the

residential neighbourhoods reached by them, the docks, and the heart of the city.

With the exception of a short length, where the line passes under the Lancashire & Yorkshire Railway coal sidings, the railway is, as its name indicates, overhead, and for the most part just over the lines of the original Dock Railway, which is upon the surface. The latter railway serves for the distribution of goods by horse traction, and has also been used by passenger omnibuses, with specially constructed wheels to enable them to leave the track when necessary. They will leave the rails altogether upon the completion of the Overhead Railway, which will afford a means of transit at least three times as rapid. The Dock Railway will then be available exclusively for goods.

The Overhead Railway consists generally of plate iron girders supported upon channel iron columns, and carrying an iron flooring, upon which the permanent way is laid direct, without the usual intervening ballast. The normal spans are 50 feet, but there are some of 100 feet, with bowstring girders, and others of special construction for opening and affording a passage to the docks for exceptionally bulky goods, such as marine boilers, &c.; thus there is a tilting bridge near the Sandown Dock, and a swing bridge of novel construction, and worked hydraulically, crossing the entrance to the Stanley Dock. This is the only dock entrance crossed by the railway, the other docks being on the river side of it.

The columns are grouted into cast iron sockets, bedded in and bolted to masses of concrete, forming the foundations.

With the exception of some half-a-dozen spans, the line has been constructed without the use of scaffolding, and with very little interference with the traffic, either of the docks or of the streets.

This important end was attained by adopting a construction which admitted of each span and its flooring being put together at one end, and transported as a whole over the already completed portion of the railway.

A depôt was established at the north end of the railway, where the flooring was constructed and riveted together, and to the main girders. The whole span was then raised by jacks; a steam trolley with wheels running upon the two rails nearest the main girders (and thus having a gauge of 16 feet), was run under the span,

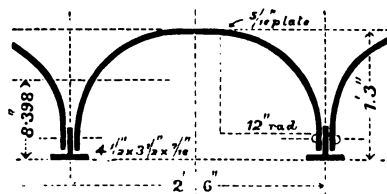
which, being lowered upon the trolley, was carried by it at such a level as to clear the main girders to the southern end of the structure. Arrived at this point, the span was slung upon a movable gantry, and by it deposited upon the columns prepared to receive it. In this manner, span after span was added, as many as twelve being placed in a week, representing a length of 600 feet of railway.

Photographs illustrating the operations of construction and portions of the railway accompany the paper, and the details of construction of one of the normal spans are shown in the accompanying drawings, and do not therefore require description.

The decking is of arched plates, finishing to 2 feet 6 inches wide and 15 inches deep, made water-tight by asphalt placed in the V-channel between the arches; this form of flooring (known as Hobson's arch plate system), first used on this railway, is being extensively used elsewhere. It is, for its weight, of great strength and stiffness, and is readily made water-tight.

The flooring is made of ordinary iron plates and tees. The plates are 46 inches wide by $\frac{5}{16}$ inch thick, and vary in length from 22 to 27 feet. The tees are $4\frac{1}{2} \times 3\frac{1}{2} \times \frac{7}{16}$ inches section, and are of lengths corresponding to the plates.

A cross-section is as shown in the following figure:—



LIVERPOOL OVERHEAD RAILWAY.
SECTION OF FLOOR.

In order to ascertain the exact strength of the floor, some actual sections were tested to destruction, and the deflections at each increase of load were carefully tabulated with the following results:—

- Test.**—*a.* Three sections of floor measuring 7 feet 6 inches in width.
b. Span, 22 feet, ends resting upon supports.
c. Load distributed over four points corresponding with the positions of the rails.

Test Load.	Deflection at Centre.
30 tons	nil
35 "	$\frac{1}{4}$ inch
40 "	$\frac{7}{16}$ "
50 "	$\frac{9}{16}$ "
60 "	$\frac{3}{4}$ "
70 "	$1\frac{1}{8}$ "
80 "	$1\frac{1}{4}$ "
90 "	$1\frac{3}{4}$ "
100 "	$1\frac{5}{8}$ "
110 "	2 " (limit)

The floor plates ultimately collapsed by the total rupture of the T-irons at 163 tons, and with a deflection of 10 inches.

It is hoped that members may be able to see the actual construction of the decking at the north end. A short description may, therefore, be of interest. The flat plates are delivered sheared to exact length and width. Six of them at a time are heated in a long oven (to a cherry-red heat), whence they are separately hauled out endways into a hydraulic press, which bends them to the required shape. After cooling upon a grid or frame, where they are tightly held to prevent change of form, they are taken to a multiple drilling machine, which drills the requisite rivet-holes (about two hundred) in two operations and in fifteen minutes. After the end angle irons, for attachment to the main girders, are added, the decking is completed by riveting mechanically the curved plates to the T-irons forming the lower member.

These combined operations are performed at the rate of forty to forty-five plates per day, sufficient to cover an area of more than 2300 square feet.

There are to be fifteen stations. They are built upon iron girders and columns, the platforms being about 115 feet in length by 12 feet wide, and 3 feet above rail level. Access to the platforms is gained from the street level by four staircases at the more important stations, and on each platform a waiting shed is provided with pay-offices and turnstiles.

An extensive carriage shed is erected near the Hornby Docks, with five lines of way running through at the same rail level as the main structure of the railway; and underneath, on the ground floor, is the repairing shop, to be equipped with the necessary tools.

The railway is to be worked by electricity, generated at a

station, for which twelve of the arches, forming the viaduct which carries the coal sidings of the Lancashire & Yorkshire Railway, have been utilised, near the Bramley Moor Dock, and about the middle of the line. At this station are three engines, each capable of working up to four hundred indicated horse-power, and each driving a separate Elwell-Parker dynamo. The electricity will be carried north and south along the railway by a steel conductor, placed on porcelain insulators, supported upon cross timbers between the rails of each line.

Hinged collectors of cast iron, sliding upon this conductor, will make the connection between the motors upon the train and the dynamos at the generating station. The motors are not placed (as on the City & South London Railway) upon a separate locomotive, but are carried by the passenger carriages themselves.

A train will consist at first of two carriages, each to seat fifty-six passengers, and provided with a motor at one end. The carriages will be so coupled as to give a motor at each end of the train, and the motors will be so connected together as to be controlled from either end by the driver, who will always travel at the front end, changing ends upon arrival at a terminus, and carrying with him a key, without which the motors cannot be operated.

All the carriages will be exactly alike, and will contain compartments for two classes of passengers, with through communication from end to end of the train under the control of the guard. A train loaded with passengers will weigh about 40 tons. The trains will be lighted by electricity, and are fitted with the Westinghouse brake, deriving its compressed air from a reservoir on the train, the reservoir being charged after each journey. This system of working the brakes has been found to answer well on the City & South London Railway. The generating station will contain at first six boilers of the Lancashire type, each 30 feet long by 8 feet diameter, with a working pressure of 120 lbs., and stoked mechanically. The engines are horizontal, compound, condensing, by Messrs. John Musgrave & Sons, Bolton. It is intended to commence running with a five-minutes' service of trains, but the generating plant is designed to be capable of working a three-minutes' service, and the journey from end to end of the railway (inclusive of stoppages) is to be performed in less than half-

an-hour. There are thirteen stations upon the dock portion of the line, and a novel feature on the railway will be a system (Timmis's) of automatic signals at all the intermediate stations, in place of the ordinary signalling arrangements. These signals will be electrically worked by the trains themselves, and considerable saving in the working expenses will result.

The permanent way, it will also be noticed, is of a novel construction. Longitudinal sleepers, resting directly upon and keyed to the arched decking, support the rails and the electric conductor. As already stated, there is no ballast between the permanent way and the structure, and the working charges in connection with the maintenance and repair of the permanent way should be exceptionally light.

The total cost of the railway, including equipment, will be about £85,000 per mile.

Mr. J. W. Willans is the contractor for the works, and the Electric Construction Corporation, Limited (Wolverhampton), are providing the electrical equipment and the carriages, under the management of Mr. Thomas Parker.

The engineers, Sir Douglas Fox and the author have been represented on the work by Mr. Francis Fox and Mr. S. B. Cottrell. Mr. F. Hudleston has had charge of the work (for Mr. Willans), and to him is due the credit for the design of the tilting and swing bridges referred to.

It is intended to open the line for traffic very shortly.

DISCUSSION.

Mr. LEWIS RICHARDS inquired if there was any provision made for expansion and contraction, of which he said there was no mention in the paper?

Mr. P. F. NURSEY asked what provision was made for the absorption of sound? It appeared to him that the line would be liable to create a large amount of noise.

Mr. GREATHEAD, replying to the question as to expansion and combustion, stated that the girders were fixed at one end rigid to the columns, but at the other end the holes were slotted, and they were free to move slightly. The girders were not continuous, a space being left between them. As regards noise, he did not expect there would be more than on an ordinary railway carried over metallic roads.

Mr. JEREMIAH HEAD asked what provision there was for drainage? He also asked Mr. Greathead whether, in advocating iron for such railways, he meant iron as distinguished from steel, or as distinguished from masonry or timber?

Mr. GREATHEAD answered that provision was made for drainage by cutting at each of the V's, which were partly filled with asphalt, a hole into which a small tube is screwed. These tubes would carry the water by a pipe at each column to the drainage below. He had advocated iron as distinguished from masonry.

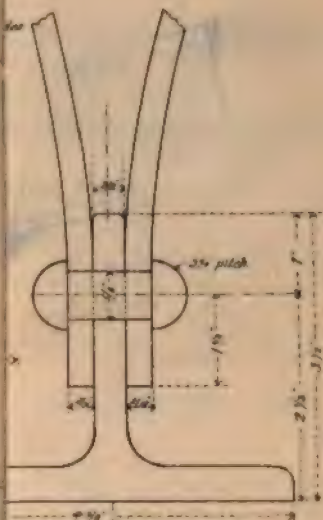
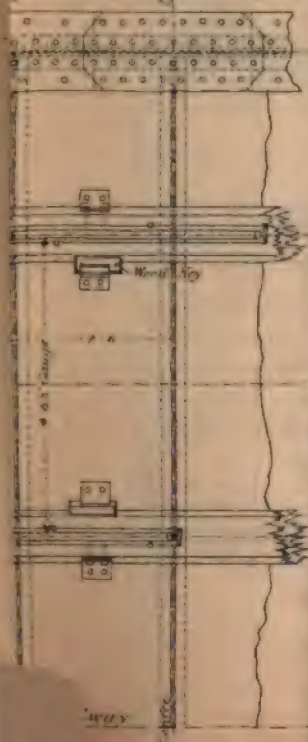
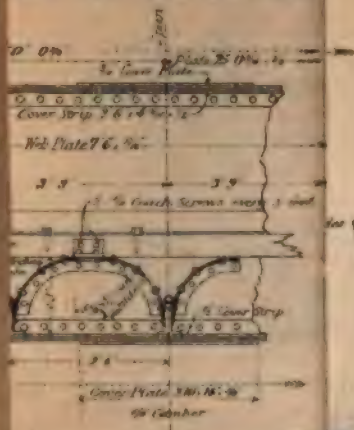
The PRESIDENT was sure that it would be the desire of the members to thank Mr. Greathead for his description of a structure which many of them would visit that afternoon with very great interest. It was a new type of structure in this country, and they would watch its development with interest, especially as there appeared to be a prospect of its being ere long introduced into the metropolis.

WEDNESDAY, SEPTEMBER 21st.

THE proceedings of the INSTITUTE were resumed to-day — Sir FREDERICK ABEL, K.C.B., F.R.S., President, occupying the Chair.

HEAD RAILWAY—
IRE OF 50 FT. 13 12

PLATE I.



Iron for Flooring.
(Enlarged Detail.)

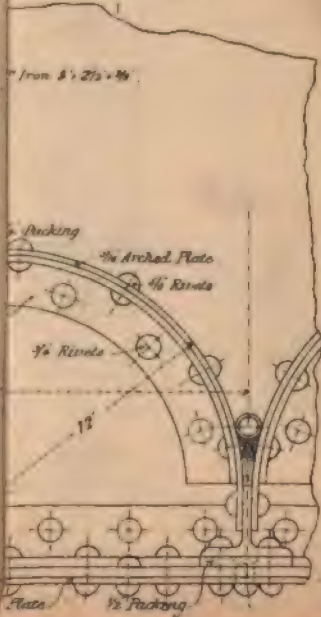


PLATE II.



ALLOYS OF IRON AND CHROMIUM.

By R. A. HADFIELD.

INCLUDING A REPORT

By F. OSMOND.

INTRODUCTION.

ALTHOUGH there have been several contributions to this Institute on the subject of the alloys of chromium and iron, notably those by M. Brustlein and M. Boussingault, so far no exact statements have been presented as to the properties of chromium steel. There has certainly been no complete record as to the effect of gradually increasing percentages of chromium upon the metal iron, and no series of tests and analyses have yet been available.

The principal object of this paper is to describe the results obtained with combinations of iron and chromium, carbon being necessarily present, but kept within as low limits as practicable with the ferro-chromium available. The experiments have been carried out on lines similar to those previously described by the writer to this Institute with regard to the alloys or combinations of iron with manganese, silicon, and aluminium.

Though it is not here attempted to deal with chromium steel as a whole, that is, carbon combinations of chromium steel, still it is hoped that they also will be found touched upon at sufficient length to convey some useful idea of their properties.

Judging from the results of the tests given in this paper, it is probable that chromium steel has an important future before it, and it is hoped that this paper may be the means of drawing further attention to the subject.* The writer cannot but think that the special question of steel alloys or combinations will be eventually found to possess considerable practical importance to the world at large, and perhaps be the means of eventually en-

* It has been recently stated, with what truth the writer does not know, that a well-known French firm partly bases the excellence of its turrets and forts on the fact that the plates for them were of chromium steel.

abling our civil and mechanical engineers to design and carry out works of a magnitude which, notwithstanding the great strides made during the last few years, even at present are not possible.

When it is borne in mind through how many difficulties the metal known as carbon steel has had to struggle, and for how long a period it has had to undergo trial and examination, it is not surprising that the introduction of special combinations, such as manganese, nickel, and chromium steel, takes place but slowly.

EARLY HISTORY.

It is specially interesting to follow the history of an important element *ab ovo usque ad mala*. In the metal chromium we have a peculiarly favourable opportunity of doing this, and one that does not occur with many of the metals.

It is to France, whose metallurgical productions, if deficient in magnitude, are not wanting in quality, and where we find so often the combination of scientific and technical knowledge, that we are indebted for most of our information as to the metal, its properties, and the development of its use. Commencing with its discoverer, Vauquelin, there followed Berthier, Frémy, Boussingault, and finally Brustlein, who has done so much to develop its applications to uses in which this Institute is largely interested. The able work of the latter was two years ago specially recognised in France by the "Société d'Encouragement pour l'Industrie Nationale," who awarded him a prize of 2000fr., "pour la fabrication courante d'un acier ou fer fondu doué des propriétés spéciales utiles, par l'incorporation d'un corps étranger." The special metal he produced was a chromium steel.

The birth of the metal occurred at the end of 1797, during troublous times, and we are reminded of contemporaneous history when we find that its discoverer, "Citoyen" Louis Nicolas Vauquelin, read his first paper* on "11me Brumaire," and his second paper on the "30me Nivôse, An. VIme," respectively, pithily entitled by Carlyle in his chronicles of those stirring times "Foga-

* "Mémoire sur une nouvelle substance métallique contenue dans le plomb rouge de Sibérie, et qu'on propose d'appeler Chrôme, à cause de la propriété qu'il a de colorer les combinaisons on il entre, par le Citoyen Vauquelin, lu à la première classe de l'Institut National, le 11 Brumaire, An. 6."

rious and Snowous Months," that is, during the second and fourth months of the year Six of the French Republic. In other words, his second and most important paper was given on January 19, 1798, and entitled "Sur la nouvelle substance métallique contenue dans le plomb rouge Sibérie, découverte par le Citoyen Vauquelin, et à laquelle il a donné le nom de Chrôme" (*Annales de Chimie*, 1798).

Vauquelin was led to the discovery of chromium as follows:—In 1789 a Paris doctor, "Citoyen" Macquart, and himself, were asked to make an analysis of the "plomb rouge de Sibérie," a native chromate of lead from that country. In 1797 he was led to believe his former results were incorrect, and said, "Owing to want of sufficient material, I have not been able to give to my researches all the inquiry I propose; still they have been sufficient to prove that this 'plomb rouge' contains a new metallic acid, possessing very marked characteristics, and of whose properties we can make use in the arts." This "plomb rouge" is now known as "Vauquelinite."

In the meantime, with his characteristic energy, only two months later, in a second communication to the Académie des Sciences, Paris, he had separated the metal, classified it, and determined most of its properties; in fact, his knowledge of the metal and the classification of its properties appear practically to be as we have them now.

It is striking to find, with the comparatively crude means then at hand, how exactly his descriptions agree with the latest data as to this metal and its combinations.

He stated that the then new metal, of which samples were exhibited before the Académie des Sciences, was white, brittle, very infusible, crystallised in *needles*,* and that acids had very feeble action upon it. His own opinion was that the brittleness and infusibility of the metal did not promise for it a great employment, but he pointed out that probably when larger sources of the metal and its oxides were obtainable, it might be applied with advantage in the arts on account of its furnishing very beautiful and durable colours in painting and enamel-work. He pointed out that the emerald owed its brilliant colour to the oxide of this metal. Its discovery has been of considerable importance, as

* This is one of the special features of rich ferro-chromium.

indeed quantities of its compounds are now extensively used in the arts, in the preparation of pigments, in calico-printing, and in giving the fine deep grain to the enamel of porcelain and glass. Borate of chromium is employed in the manufacture of colours, used as a substitute for arsenical green in painting and dyeing.

It appears that some of his friends, "Citoyens" Fourcroy and Hanz, were consulted as to the baptism of the new metal. "Chrôme" was suggested, from the word "chroma" (colour), the "plomb rouge" from which the metal was first extracted being of a characteristic colour, and also from the various and beautiful colours which the oxides of the metal gave to the minerals and substances into whose composition they entered. It bears in this respect a resemblance to the metal "uranium."

Vauquelin very properly said, "I must confess that this title does not altogether suit the metal, since in itself it has no particular colour. I did not wish to adhere specially to this title, more than to any other which would be suitable and expressive of its most salient and characteristic properties." The advice of the two friends evidently prevailed, and thus we have the metal chromium.

It is, therefore, in Vauquelin's paper that we find the first mention of the metal "chrôme." It has sometimes been called "chromion," but now receives the termination "ium," common to many of the metals.

Vauquelin was one of the many industrious chemists from whose labours, crude as they then appeared, we are to-day reaping so much benefit. It was said of him by Cuvier, "Il était tout chimiste, chimiste chaque jour de sa vie et pendant la durée de chaque jour." His different treatises amounted to more than 240.

His scientific intuition could enable him to see ahead when he said, speaking of the discovery of the metal, "I venture to say that if chemistry could only utilise but a few of the many objects that Nature offers to us, it would soon convert into useful applications bodies which now exist only as a vain curiosity." No doubt Vauquelin would be surprised if he could see that to-day we are principally indebted to the metal he discovered, now nearly a century ago, for the remarkable properties possessed by modern armour-piercing steel projectiles—properties that have enabled those of 6-inch calibre, such as are described more fully later on,

to penetrate compound armour plates $10\frac{1}{2}$ inches in thickness, remaining practically unaltered in form, or those 13.5 inches in diameter, fired from the 63-ton B.L. gun, to penetrate over 3 feet of steel and wrought iron.

If he could have seen these proofs, he would have felt that the brittle metal extracted from "plomb rouge" possessed influences that he had little dreamt of, rendering possible the penetration of modern armour, whether of iron or steel, and of thicknesses which but a few years ago were considered impregnable.

The application of this metal in metallurgy to more peaceful purposes has not yet been extensive, but that its use will increase cannot be doubted in face of the results of Brustlein and others. Although this extension may not proceed rapidly, there is, without doubt, a place for its further useful employment.

DESCRIPTION OF THE METAL.

The metal chromium, symbol Cr, has an atomic weight of 52.40;* atomic volume, 7.7; specific gravity is stated as low as 6.80 and up to 7.3; specific heat estimated at 0.12. Its melting-point has not yet been determined. Some say it is higher than that of platinum. Deville stated that he obtained chromium which was less fusible than platinum. Carnelly, in "Melting and Boiling Points," says, "Chromium does not fuse in the forge, but softens and conglomerates." Neville, "melts above platinum." These statements, being comparative and approximate, are not of much actual service. Probably the melting-point is somewhat higher than that of pure iron, judging from M. Osmond's experiments given in Table XII.

Though Mr. J. F. John, in a paper to the Academy of Science, September 1821, stated that he found traces of chromium in meteoric iron, it has probably never been found in the native state, and has usually to be obtained by reduction from its oxides. In its actual metallic state it may be safely described as one of the "rare" metals, the writer having paid for a small sample of the supposed metal at the rate of 80s. per oz. Even this sample

* In *Zeitsch. für Anal. Chemie*, xxxi. part 1, it is stated that Meineke finds the general mean result = 51.94, which agrees well with that of Rawson, 52.61, especially if it is considered that, if reduced to a vacuum, it exceeds 51.98.

contained only 86.60 per cent. chromium, and as much as 2.18 per cent. carbon. This being material sold as the actual metal, its exact properties can hardly be said to be known with certainty. The sample containing the above percentage of chromium was of 7.87 specific gravity and non-magnetic.

In Watt's "Electro-Deposition" mention is made of a plan adopted by Bunsen for procuring chromium by electrolysis. It appears he separated the chromium with facility from a concentrated solution of its chloride. The deposited metal, which is said to have been chemically pure, presented the appearance of iron, but was less alterable in moist air. It resisted the action of even boiling nitric acid, but was acted upon by hydrochloric and dilute sulphuric acid. Bunsen found that when the current was diminished, the metal ceased to be deposited in the metallic state, but appeared as a black powder consisting of protoxide and sesquioxide of chromium. Further particulars are given in Appendix A.

A sample supplied as very fine powder by Messrs. Königswater and Ebell, of Linden, Hanover, to the writer, and containing 75 per cent. of the metal, was found to turn green after a few weeks' exposure to the air.

By some it is stated that the metal is easily oxidised owing to its affinity for oxygen; by others, that this is not so, and that it suffers but little change when exposed to the air. It has also been stated that the metal has been obtained in several modifications, one of which is so refractory as to be infusible at a temperature sufficient to volatilise platinum.

Chromium, as we know it from the samples sold in the metallic and solid form, may be heated to redness without oxidation, and resists the action of most acids. Frémy is stated to have obtained crystallised chromium which was unattacked by the strongest acids.

In the powder form it is stated to be amorphous, burns brilliantly when heated in air, and is readily soluble in acids. Probably this is the form mentioned by Wöhler, who, in reducing its sesquioxide with zinc, obtained it as a shining green powder of 6.81 specific gravity, which easily tarnished in the air, and is dissolved in HCl and warm H_2SO_4 . This corresponds in properties to those noted in the Hanoverian samples.

Mr. James Park, Millburn Chemical Works, Glasgow, in 1888 took out a patent (No. 377-88) for improvements in the manufacture of metallic chromium. This inventor uses bichromate of potassium, converts it into oxide of chromium by suitable preliminary heating along with sugar, the material being first intimately associated in a state of fine division. This product is then reduced with the metal by mixing with charcoal or other forms of carbon, and, after fusion, the spongy chromium obtained is finely pulverised and again fused at a very high heat, and a mass of pure, or nearly pure, chromium is obtained. It should, however, be stated that the samples given to the writer made by this process were found on analysis not to contain more than 79 per cent. chromium, the remainder being iron, silicon, and carbon. Full analysis of this is given in Table XIII., and further information in Appendix B.

Dr. Glatzel, by reducing potassium chromic chloride with magnesium in the presence of potassium chloride, obtained chromium consisting of microscopic crystals almost white. When rubbed in an agate mortar they showed metallic lustre. The specific gravity at 16° C. was 6.7284 (Wöhler found 6.81 at 25° C., and Bunsen 6.7). The magnet had no effect on the metal. Dr. Glatzel having made so many interesting experiments in the production of pure metals, it has been thought worth while to give his methods in full at the end of this paper. See Appendix C.

The oxides of this metal are chromous oxide or protoxide of chromium (CrO) of bright green colour. Chromic acid or chromic sesquioxide (Cr_2O_3), or more properly chromic oxide, destroys the colour of indigo and most vegetable and animal colouring matters, and is advantageously employed in calico-printing. It forms coloured salts with alkaline bases, the most important of which is chromate of lead, which has a rich yellow colour. Chromate of iron affords a beautiful and durable pigment. The chromites are a class of bodies in which chromic oxide, Cr_2O_3 , is united with protoxides, as in the combined Cr_3O_4 , and in chrome ironstone, $\text{Cr}_2\text{Fe}_3\text{O}_4$. The latter, the most abundant ore of chromium, contained, besides iron and chromium, varying proportions of magnesia and alumina. It is massive, compact, and granular; it rarely crystallises, and is a black-coloured mineral of 4.40 specific

gravity. It usually occurs in serpentine, also in chrome ochre, Cr_2O_3 , ouvarovite or chrome garnet, $\text{Si}_3\text{CaCr}_2\text{O}_{10}$. There is also crocoisite, PbCr_3O_4 , in which the metal was discovered by Vauquelin, and yet another form, which took its name from Vauquelin, called Vaquelinite, a chromate of lead and copper. The green colour in serpentine, pyrope, and emerald, comes from the combination of this metal. Chrome iron ore is probably the most abundant source of this metal.

EARLY EXPERIMENTS.

As regards the earliest experiments with reference to the addition of chromium to iron and steel, it appears that Faraday and Stodart in 1820 were the first investigators. At that time considerable attention was being paid to the subject of alloys, and Faraday, knowing that chromium was then comparatively a newly discovered metal, and believed to be of very hard nature, no doubt thought that its addition to iron or steel would confer beneficial hardness for tools and other uses, and that it might take the place of carbon. This, as will be seen from the writer's experiments, cannot be so; chromium *per se* does not confer hardness.

An interesting account is also given by M. P. Berthier,* who made a considerable number of experiments detailed in the *Annales des Chimie* for the year 1821. He there very frankly states that the idea of introducing chromium into steel had been suggested to him by Faraday's interesting paper upon "Alloying different metals with steel." This statement is important, as elsewhere it has been stated that Faraday obtained his idea from Berthier's work.

Berthier's experiments were, however, much more exhaustive than Faraday's, and in a paper of considerable length he gave many interesting facts respecting his experiments. He found that the presence of iron facilitated the reduction of oxide of chromium, though very considerable heat was required. His experiments were carried out with ore containing 36 per cent. of oxide of chromium, coming from Ile à Vaches, a small island south of St. Domingo. He made alloys of ferro-chromium containing 17 per

*ur les alliages du chrome avec le fer et avec l'acier" (*Annales des Chimie*, i. 1821).

cent. chromium, and also other special samples, said to have contained as high as 60 per cent. chromium. After producing his ferro alloy, he made chromium steel of 1 per cent. and $1\frac{1}{2}$ per cent. chromium, but the only special quality of the product he particularised was that of damascening. He stated that the damask showed "a variegated face of silvery whiteness, the white parts probably being pure chromium, upon which we know that acids have no action."

He concluded his report by saying that he had spent much care on the preparation of ferro-chromium, not because he believed such material had in itself special value, but because he believed it would be found useful as a means of introducing chromium into cast steel.

Both the 1 per cent. and the $1\frac{1}{2}$ per cent. steels he produced were stated to forge well. Knives and razors were made, the blades of which were reported as being of good quality. No analyses are given, nor even an approximate idea as to the amount of carbon also present in his samples, so that it is impossible to know what were likely to be the characteristics of the material produced.

It is unfortunate that Baur, in his practical work some forty years afterwards, did not recognise the value of—perhaps he was not aware of them—Berthier's experiments. Baur's early attempts had in view the object of combining chromium directly with iron or steel by means of *ore* additions. After several years of experimenting he had to come back to the very method indicated by Berthier, being the one now always followed, that is, introducing chromium into steel by means of ferro-chromium of known and certain percentage, and thus doing away with uncertainty as to the character of the product.

Attention was given to chrome ores some forty years ago. Sir F. Abel, in his presidential address to this Institute in 1891, makes an interesting reference to the fact that in his early student days (1846) it was considered that one of the most difficult tasks to set a young analyst, after the completion of his course of practical study, was the complete analysis of a sample of chrome iron ore.

Experiments with the metal then seem to have ceased until

1857, when Frémy* obtained the metal by Wöhler's method. He pointed out a fact that applies with equal force now, viz., how much is wanted to establish a correct classification of metals, for although chromium belongs to the iron group, its properties vary considerably from those of other members of the same group. For example, one striking difference is its insolubility in the presence of concentrated acids, a fact in which it rather resembles rhodium and iridium, members of quite a different group.

Frémy mentioned another fact which will be referred to more fully under the division relating to ferro-chromium, and a point which is also referred to by M. Brustlein in his paper to this Institute a few years ago, viz., that the chromium in ferro-chromium possesses the property of crystallising in long needles.

Frémy's experiments are of interest, although it is not clear that he actually carried out the suggestion, from the fact that they led him to suggest that ferro-chromium should be made in the blast furnace, by heating together chromium oxide with metallic cast iron or with suitable iron ores.

Dr. Percy was probably the first Englishman to experiment upon the production of rich alloys of ferro-chromium. These he made in small quantities on a laboratory scale, commencing with 4 per cent., then 27 per cent., 54 per cent., and 76 per cent. chromium. The iron only having been determined in the richer percentages, these analyses must, however, be taken as approximate. Although the amount of carbon in his samples is not stated, it was probably high, judging from the description of the properties of the material produced. He stated the 4 per cent. and 27 per cent. *were*, but the 54 per cent. and 76 per cent. *were not* attracted by the magnet. In this respect, however, both M. Brustlein's and the writer's observations do not coincide with the foregoing. This point will be found fully mentioned under the section relating to the magnetic properties of ferro-chromium.

Patent specifications generally reveal the history of early experiments, and those relating to chromium form no exception.

In 1861 we find the first commercial application of chromium to iron and steel manufacture suggested by Robert Mushet, who did so much valuable work as regards alloys of iron and steel.

* *Comptes Rendus*, vol. xliv.

His proposal was to heat lumps of pig, cast, or refined iron, to a temperature somewhat short of their melting-point, then pulverise them along with powdered wolfram or tungsten, or powdered chrome ore, or oxide of chromium. It is difficult to understand what advantages such treatment offered.

In 1870 Mr. A. Parkes, a then well-known worker in alloys, speaks of using chromium as an alloy, but it is not clear whether he ever carried out his ideas on a practical scale.

Mr. H. Biermann of Hanover, whose smelting-works are in France, states that he produced ferro-chromium commercially as far back as 1873. In July 1877 he supplied to the writer's firm 10 to 30 per cent. ferro-chromium, the higher percentages costing 2s. per lb.

As the foregoing experiments were but tentative, after considerable investigation the writer is led to the conclusion that it is to Mr. Julius Baur of New York to whom the credit must be given of first introducing on a practical scale the manufacture of chromium steel. M. Brustlein has frankly admitted that he was in 1875 led to make his own experiments from seeing an account of Baur's work in America.

Mr. Baur took out an American patent in August 1865 (No. 49,495), claiming "A steel greatly improved, toughened and hardened by the addition of chromium, and also claiming to be the first to establish the fact that chromium can be used practically in making steel." In 1869 he patented further improvements, and some years later an improved method of making the ferro-chromium to be used. Since then, it is stated, his process has been continuously carried out by the Chrome Steel Company, Brooklyn, N.Y., who also exhibited numerous samples of this steel at the Centennial Exhibition in Philadelphia in 1876, consisting of ferro-chromium, chromium steel drawn into bars, and plates of soft iron and chromium steel welded together. This company produced their own ferro-chromium from the commencement of their manufacturing chromium steel, and this, no doubt, was the reason of their greater success. In a letter to the writer from this firm, in April last year, they state that they had produced chromium steel for the last twenty years, and that Mr. Haughian, their vice-president, had also contributed to the im-

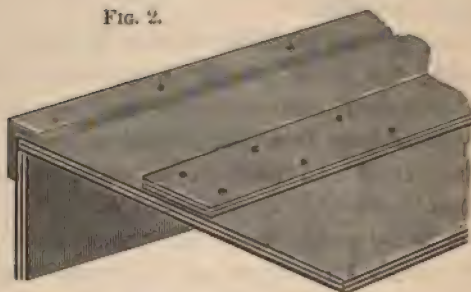
provements in the manufacture of this steel during the early stages of the invention.

In an amusing little pamphlet, "The Jail-Breaker's Catechism," kindly forwarded by this company, a supposed burglar, after describing how he had escaped from other jails, explains that he is now in prison owing to the superiority of chromium steel jail bars. The particular manner in which these bars are made is illustrated by Figs. 1 and 2.

FIG. 1.



FIG. 2.



A similar process of producing carbon steel plates and bars, intermingled or welded to wrought iron, is carried out by several Sheffield firms. The product is also principally used by safe-builders.

The New British Iron Company have made a special study of composite steel.

Mr. Baur, in his early specification, described his method of making chromium steel by means of chromium iron, mixed with the iron or steel to be treated, and, like other experimentalists,

claimed to use chromium as a steel-making element, that is, to take the place of carbon, and "that the metal produced derived its steely qualities solely from the metallic chromium present in it, and not from the carbon." It will be seen from the experiments detailed in this paper that this view was incorrect, and that chromium alone does not give "steel-like nature," that is, using this term to describe the property of the product becoming hard when rapidly cooled.

It was not until about 1876 that Baur found the direct alloying of the chrome ore with the iron or steel under treatment was so uncertain as to render the product of little value, and that a ferro-chromium must be employed to ensure a reliable result. As before pointed out, Berthier, in 1821, had foreseen the importance of the production of a regular and reliable ferro-chromium, and seeing the very clear manner in which he had at the time put forward his reasons, it is surprising to find that this point was overlooked by Baur and others.

M. Brustlein's work and investigations—which commenced in 1876—respecting chromium steel, are so well known, having been communicated to this Institute in 1886, that it is not necessary to refer specially to them here. His views on certain points will be dealt with at length in other sections of this paper. His firm, Messrs. Holtzer & Co., of Unieux, exhibited at the Paris Exhibition, 1889, a very fine collection of tensile and other test-pieces (see Table XIV.). Most of these were prepared from chromium steel. As they do not appear to have been printed in any English metallurgical work they are added in the Table named. Being unaccompanied by any analyses, in order to make the record more useful, perhaps M. Brustletin may see his way to complete this interesting series by adding the chemical composition.

These and the tests detailed in this paper would then put on record a very complete set of tests and analyses relating to the interesting alloy known as chromium steel.

Mr. Sergius Kern of St. Petersburg has also experimented with chromium steel, and quite recently an excellent paper by Messrs. Franklin Hart and Julius Calisch, of the Stevens Institute of Technology, gives much useful information on this subject.

FERRO-CHROMIUM—ITS PRODUCTION, AND THE SOURCES OF THE
ORES USED IN ITS MANUFACTURE.

The first step in the manufacture of malleable alloys of iron and chromium, in other words, chromium steel, is to obtain reliable and uniform ferro-chromium. As pointed out, attempts were at first made to obtain the direct combination of chromium and iron by means of chrome ore melted along with or added to the molten bath under treatment. But this, whether with the crucible or other process, is practically out of the question. Baur's early attempts were in this direction, but until he had made a satisfactory ferro-chromium no success was achieved.

The production of ferro-chromium is accomplished in several ways, the principal of these being the crucible and the blast furnace methods. The former, being naturally expensive, is confined to making material of very high percentages. Several firms manufacturing chromium steel produce their own ferro-chromium, but it is now a regular article of commerce, and can be bought in varying percentages up to as high as 70 per cent. Percentages even as high as 80 and 84 have been obtained, but only experimentally. The cost of the higher percentages is still great, but no doubt if a large demand were to spring up, owing to the many sources available for obtaining the ore, a considerable reduction could be made.

In passing, the writer, as one of those indebted, would like to offer his thanks to the courageous band of men who, at much cost and labour, have perfected from time to time the manufacture of special ferro-alloys. The steel-maker would not to-day be in the position he holds, except for the fruits of such labours. One does not often hear their names mentioned, but had it not been for their help, the steel industry of to-day would not have progressed so rapidly, or have been so advanced as it now is. Such experimental work as the writer and others have carried on from time to time, in the hope of determining the actual properties of different elements alloyed with iron, would have been impossible except for the assistance of these workers.

ing with Messrs. D. & R. Mushet, we then have

Mr. Henderson, who worked for so many years, and laid the foundation of the present successful production of the now invaluable alloys of ferro-manganese. His labours were continued at the Terre-Noire Works by that progressive band of metallurgists—Messrs. Euverte, Pourcel, and Gautier, and eventually by several firms in this country, including Messrs. the Darwen and Mostyn Co., the Wigan Coal and Iron Co., and others.

In silicon and silicon-spiegel alloys, the work has been ably carried on in this country by Messrs. the Darwen and Mostyn Co., Darwen; Gjers, Mills, & Co., Middlesbrough; Dixon & Co., Glasgow; Mr. Crossley of Glasgow, and Mr. Hewlett, of the Wigan Coal and Iron Co.

The Darwen and Mostyn Co., assisted by Mr. Holgate, has also for several years past developed the manufacture of ferro-chromium in this country; whilst abroad, Biermann of Hanover was probably the first to take up its manufacture about 1873.

Later, we have the aluminium and ferro-aluminium products, the manufacture of which has been brought to such perfection by Messrs. Hall & Hunt of the Pittsburgh Reduction Co., the Cowles Co., the Aluminium Co., and others.

Chrome iron ore is the most abundant source of this metal, and is found in the Shetland Isles, Uist and Fetlar; near Portsoy in Banffshire; the Department of Var, France; Silesia and Bohemia; Greece, Asia Minor; the Ural Mountains; New Caledonia, where large deposits are said to exist; Maryland, U.S.A.; Sydney, N.S.W.; and California. The latter State has during the last seven years raised about 15,000 tons, valued at \$270,000. The ore contains about 40 per cent. to 50 per cent. of the oxide. It is found in irregular masses, disconnected and embedded in the country rock in varying quantities. The American mining operations of this ore are, however, reported to have suffered from foreign competition since 1884, and are becoming much less. In 1888 that country imported chrome ore to the value of \$46,000. Large supplies now come from Asia Minor, where it is mined at Brusa and Harmanjick, about sixty-five miles south of Pera. The deposits there are also found in irregular pockets, contained in serpentine. Boussingault states in his paper to this Institute that chrome ores are always mixed with considerable amounts of ferrous oxide, 10 to

20 per cent. of magnesia, the silica and alumina being usually under 10 per cent.

Mr. Pemberton,* in a paper to the Columbia College, U.S.A., in March 1891, mentions that according to the State mineralogist of California, large quantities of chromite beds were found there, existing as loose and fragmentary rocks in the ravines and on the hillsides, and as pockets and veins on the mountains. One of the best mines is situated at an elevation of 1800 feet above sea-level. The sample of this chromite gave the following analysis:—

Cr_2O_3	Al_2O_3	Fe_2O_3	MgO	FeO	MnO	SiO_2	H_2O	Total
52.68	11.40	3.52	16.23	11.77	0.15	3.40	0.95	= 100.09

In a paper read at the Baltimore meeting of the American Institute of Mining Engineers, in February last, Mr. G. F. Kunz gave some interesting information and analyses of a Bohemian garnet which contained chromium oxide. This garnet is the blood-red pyrope variety (magnesia-iron-lime-alumina garnet), with a hardness of 7.5 and a specific gravity of 3.7 to 3.8, and not the purple almandine, which is an iron-alumina garnet, with a specific gravity of 4.2. The following are the most important analyses published:—

	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	FeO	MnO	Cr_2O_3	Total	Incl.	Mn_2O_3
I.	40.00	28.50	16.50	10.00	3.50	...	...	2.00	100.75	0.25	...
II.	43.70	22.40	...	5.60	6.72	11.48	3.68	6.52	100.10	...	...
III.	42.08	20.00	1.61	10.20	1.99	9.09	...	3.01	93.20	0.32	...
IV.	41.35	22.35	...	15.00	5.29	9.94	2.59	4.17 ²	100.69	...	...

- I. Klaproth, "Beitr. Chem.-Min.," 1797, ii. 21 and 1810, v. 171.
- II. Trolle-Wachtmeister, "Vet. Ak.," Stockh., 1825, 220.
- III. Kobell, "Kastn. Arch. Nat.," ix. 344.
- IV. Moberg. (Moberg estimates the chromium as CrO in this and other pyropes.)

In a recent communication to the writer, Messrs. Busek & Co. of Vienna offered chrome ore containing about 38 per cent. Cr_2O_3 , at 33s. per ton f.o.b. Orsova.

M. Boussingault, in the paper before mentioned, stated that he noticed during his stay at Antioquia, Central America, that chrome ore existed in abundance in the land on which smelting-

* "Analysis of a Chromite," by Mr. H. Pemberton, junr. Paper read at the Columbia College, Chemical Section, March 1891.

works were there built, the walls of the houses being built of the chrome ore. He also claims that chromium pig was obtained there from the blast furnace in the year 1867 by a company who erected a forge in the neighbourhood of Medellin, in the province just referred to of Central America.

Dr. Percy, when speaking of magnetic oxide of iron, states that chrome ironstone, like magnetic iron-sand, is sometimes met with in a similar state, and may be readily mistaken for magnetic iron-sand, but that it differs from the latter in being non-magnetic.

It is stated that the working of the Ural chrome iron ore into chromium compounds has been established in Russia, owing to the efforts of M. Ushakoff, who constructed works for this purpose on the river Kama, near Elabougi, where as many as 2000 tons of ore are treated yearly, and owing to which the importation of chromium preparations into Russia has ceased.

About 1872, the Tasmanian Iron and Charcoal Co., Ilfracombe, near Launceston, Tasmania, produced in their blast furnaces iron containing 6 to 7 per cent. chromium. Samples of this pig iron analysed as follows:—

C.	Si.	S.	P.	Mn.	Cr.	Fe.	Total per Cent.
4.42	1.52	.10	.05	.14	7.05	86.56	= 99.79

Only recently these mines have been again prospected. It appears that these large deposits of brown hematite iron ore contain about 3 per cent. of sesquioxide of chromium and but little sulphur and phosphorus. They have been described by Mr. Gould, Government Geologist. Mr. H. M. Johnstone, in his "Geology of Tasmania," speaks of this deposit, known as "the Hills," as being very large.

The following analyses are stated to have been prepared by Mr. Woodgate in 1880:—

	Ilfracombe.			River Don.
	Sample No. 1.	Sample No. 2.	Sample No. 3.	Sample No. 1.
Volatile on ignition	11.2	19.5	5.1	12.0
Alumina	2.0	15.3	5.8	2.4
Sulphur	Trace only	...	...	...
Phosphorus	Trace only	...	...	...
Lime—Magnesia—Alkalies . . . .	...	...	...	Traces
Chromium sesquioxide	Trace	3.0	3.4	...
Sesquioxide of iron	79.8	...	...	70.8
Peroxide of iron . . . . .	...	42.5	80.0	...
Silica	6.1	18.4	4.8	13.8
Difference . . . . .	.9	1.3	.9	1.0
Totals	100.0	100.0	100.0	100.0

*Analyses of Metallic Iron (Roasted Ore ? *) reduced from Ilfracombe Ores*

	Sample No. 1.	Sample No. 2.	Sample No. 3.
Iron	89.0	73.3	97.2
Silica (?)	3.2	19.9	.9
Graphite . . . . .	.7	.8	...
Chromium	5.1	4.6	Traces
Sulphur . . . . .	...	.2	...
Difference	2.0	1.2	1.9
Totals	100.0	100.0	100.0

Analyses of Slags.

	Sample No. 1.	Sample No. 2.	Sample No. 3.	Sample No. 4.	Sample No. 5.
Silica	34.6	28.8	33.5	32.0	26.6
Protoxide of iron	7.7	3.7	2.5	1.9	1.0
Alumina	24.1	36.2	26.6	32.1	32.2
Lime	27.1	24.8	29.1	26.7	33.2
Magnesia	2.6	3.2	2.1	2.2	2.0
Difference	3.9	3.3	6.2	5.1	5.0
Totals	100.0	100.0	100.0	100.0	100.0

* It is not clear whether they refer to a roasted ore or a badly puddled product.

It is estimated that over half a million tons (brown hæmatite ore, containing about 3 per cent. of sesquioxide of chromium, and varying in size from small pebbles up to great round boulders many tons in weight) are in sight on the surface. The mines are found in the district known as the Ironstone Hills, near the River Tamar, at Port Lampriere. They are near to the Beaconsfield Gold Mine, which to date has yielded over 400,000 ounces of gold, valued at over a million and a half sterling. Unfortunately, the chrome ore mines proved anything but a gold-mine to the Tasmanian Iron and Charcoal Co., who some fifteen years ago erected coke-ovens and a blast furnace, after Scotch designs. This was principally owing to the unfortunate (to them) property possessed by chromium of converting all the carbon present into the combined form. No other product could be obtained except a hard white pig iron, which was of but little use for foundry purposes, and could not be puddled or made into steel. The company came to grief, but several hundred tons of the pig iron were shipped to England, and as an alloy its use was found beneficial for special purposes. These experiments are referred to when considering the qualities of chromium steel.

The Tasmanian deposits being on such a large scale, it may be interesting to give a description of them.

The Ilfracombe deposit is certainly a remarkable one, and the geologist may, from the following description, form some idea as to the origin of this particular formation.

The Tasmanian Ironstone Hills, as they are called, are believed by Mr. Gould, the Government Geologist, to be of Lower Silurian age. He states that the rocks of the district are contorted slates, sandstones, and limestones. In the immediate vicinity of these deposits is a great mass of serpentine, varying through all shades of grey to green in colour, and containing many thin veins and bands of asbestos and magnetite. In several of these rocks there are extensive surface outcroppings of ironstone, pointing to the existence of large deposits of hæmatite or magnetic ore beneath. The Ironstone Hills, rising to about 100 or 150 feet above the level of the river close by, are easily distinguishable from the surrounding undulating wooded country by the deep red colour of the soil, and the pieces of ironstone range from the size of small

pebbles up to great rounded boulders, many tons in weight, with which all the surface is covered. In each case the largest of these boulders are found near the summit of the hill, where they are often heaped on one another, or protrude in great masses from the surrounding soil, which has been obviously formed by their destruction. The blocks mostly "weather" into round masses, and develop a conglomerate structure on the outside, suggestive of small fragments or pebbles of hæmatite cemented together by ferruginous earthy matter, and on breaking some of these small pebbles they show a well-marked concentric structure with earthy ochre in the middle. The flat between the two hills, and the underlying serpentine for many miles around, are also covered by a drift of ironstone, which, near the flanks of the hill, is two or three feet in depth, containing small lumps and pebbles of brown hæmatite, apparently derived from the deposits themselves. Further away, where the drift is only a few inches deep, it consists mainly of irregular lumps of fibrous magnetite of great purity, the largest lumps running up to 15 or 20 lbs. each in weight. These seem to have been derived from the disintegration of small veins in the serpentine itself.

In Mr. Johnstone's "Geology of Tasmania," certain portions of the deposits just described are stated to have analysed as follows:—

Protoxide of iron	30.547
Sesquioxide of iron	66.151
<hr/>	
Total	96.698
Difference of alumina, silica, and water	3.302
<hr/>	
In parts	100.000

The total metallic iron present is therefore 70 per cent., 23 per cent. of which exists as protoxide, and 47 per cent. as sesquioxide. In this case no mention is made of the sesquioxide of chromium. Probably the above samples are taken from the deposit of ordinary iron ore existing close by.

The chrome ore obtained at these mines is valued at about 5s. per ton at the mine, and it is estimated that delivery could be effected to this country for about 15s. to 20s. per ton.

PRODUCTION OF FERRO-CHROMIUM BY THE CRUCIBLE PROCESS.

M. Boussingault refers to a report by M. Rolland, who stated that in 1869 ferro-chromium, 21 to 26 per cent., had first been produced by Mr. Baur, of Brooklyn (N.Y.), who mixed chrome ore according to his patented process. The chromium was reduced from the serpentine of Hoboken and Newhaven, the ore being reduced to a fine powder, mixed with 6 to 8 per cent. of charcoal or pure anthracite, and a certain quantity of flux, containing calcium or sodium fluoride, to which lime or borax was added. This mixture was then melted at a high temperature in plumbago crucibles, and a ferro-chromium was obtained of percentages varying from 21 to 46.

In 1875 Mr. Sergius Kern of St. Petersburg is stated to have obtained a 74 per cent. ferro-chromium by melting in the crucible chrome ironstone from the Ural Mountains along with charcoal. In the same year M. Brustlein manufactured this material at the Unieux Works, and he has in more recent years produced samples of ferro-chromium containing as much as 84 per cent. chromium and 11 per cent. carbon. Full analyses of the different specimens will be found in Table XIII. This rich ferro-chromium has to be made from specially prepared Cr_2O_3 , which adds very much to the cost as compared with the lower percentage material made in the blast furnace. For example, by the latter system, 28 to 30 per cent. ferro-chromium has been sold at £25 per ton, whilst the 66 to 70 per cent. material, prepared in crucibles, ranges from £90 to £100 per ton. Mr. Reichwald has supplied some of this rich material, importing it from Germany. Messrs Stevenson, Carlile, and Co., of Glasgow, under Park's patent, have also made ferro-chromium up to 90 per cent., but as yet only on a small scale.

The writer made some experiments eight or nine years ago, which prove how comparatively easy is the partial reduction of chromium from the ore. About 40 lbs. of ordinary No. 1 hæmatite pig iron was melted in a crucible, and to this amount was gradually added 20 lbs. of chrome ore, stirred in during a period of an hour and a half. The result gave a chromium pig iron containing 4.37 per cent. of chromium. The grey iron was entirely changed

in its character, now showing an almost spiegel fracture. A weight of 15 lbs. of chrome ore produced a similar effect, but 10 lbs., curious to say, the experiment being twice repeated, did not change the grey nature of the pig iron, nor was any chromium reduced.

It has been stated* that Swedish ferro-chromium made by the Lyrholm Co., 60 to 70 per cent. Cr, contains a less proportion of carbon than other makes, but the writer has not had the opportunity of confirming this. The Wittenström system of furnace is employed by them as affording a specially high heat.

PREPARATION OF FERRO-CHROMIUM IN THE BLAST FURNACE.

Vosmaer's recent work and resumé of metallurgical progress† gives interesting information on this subject. He points out that chromium is not easily reduced in the blast furnace, except at high heats, the practical limit of the chromium in the ferro-alloy by this means so far having been not more than 40 per cent., though theoretically 65 per cent. should be obtainable. Chromium ore usually contains from 50 to 60 per cent. Cr_2O_3 , and about 20 per cent. FeO . The quantity of fuel consumed is even higher than that used in the manufacture of rich ferro-manganese. As much as three tons per ton of alloy produced are required; hot blast and high pressure are also essential. As is well known, chromium considerably raises the limit of carbon saturation, whether the ferro-chromium is made in the crucible or in the blast furnace, and even more so than manganese in the case of spiegel or ferro-manganese. Whilst the highest quantity of carbon present in ferro-manganese has probably never exceeded 7 per cent., the Adour (St. Chamond) 65 per cent. ferro-chromium exhibited at Paris in 1889 actually contained 12 per cent. of carbon, which is always present in the combined state. The writer has in several ways tried to produce graphitic carbon in ferro-chromium, such as by extremely slow cooling, also by adding graphite to molten ferro-chromium, but unsuccessfully. It is no doubt partly owing to this peculiarity,

* *Stahl und Eisen*, January 1888, "On the Swedish Production of Chromium Alloys."

† "The Mechanical and other Properties of Iron and Steel," by A. Vosmaer.

that, as in the case of white iron, where the carbon is in the combined form, solidification takes place very rapidly and the metal soon chills. No doubt its freezing-point is considerably higher than that of grey iron.

Although chromium ore, under proper conditions, is readily reduced, its oxide does not easily slag, and great difficulty is experienced in producing a fusible slag. The addition of large quantities of alkaline carbonate, fluor spar, borax, or lime, is necessary. Partly for this reason, all attempts to puddle chromium pig iron by itself have so far been unsuccessful, as the highly refractory slag or oxide cannot be dissociated from the metal. As before pointed out, there are excellent deposits of iron ore in Tasmania, but as they contain chromium oxide, the chromium in which is also reduced at the same time, the pig iron produced has not, so far, possessed any commercial value. A considerable quantity of this material was brought into England during the year 1878, and Mr. Riley drew attention to its special properties.* A somewhat noteworthy point was the high sulphur present, so that chromium, unlike manganese, in its action in the blast furnace, does not expel this metalloid.

Mr. Riley found in puddling a charge consisting of about one-tenth of chromium pig, the remainder being grey forge pig iron, that the process was prolonged. The chromium was found in the cinders soon after all the pig was melted. No decided effect was noticed one way or the other on the puddled bars. It was found, therefore, that whilst the chromium pig by itself could not be puddled, small quantities, mixed with ordinary pig iron, did not appear to materially interfere with the usual process.

It was also stated that chromium would not take the place of manganese, as on adding chromium pig to decarburised iron the resulting ingots crumbled under the hammer at a red heat. Seeing the very small percentage of manganese present in the writer's samples, the foregoing statement requires some qualification.

Mr. Gilchrist has made experiments in this direction, and will no doubt give his experience.

Dr. Percy, in the course of the discussion on Mr. Riley's paper,

* Paper read before this Institute by Mr. Riley on "Pig Iron made by the Tasmanian Iron Company."

said, "Some years ago he had found in Russian black sheet iron .035 per cent. of chromium," but such a small amount could have little effect.

The Tasmanian material, being useless for puddling purposes, proved to be rather a white elephant until certain steel-works found that their material was improved by its addition, and that axles made of the ordinary composition which would not pass the drop test, would successfully do so when the steel was alloyed with a suitable percentage of chromium. Professor Arnold's interesting paper to the Institution of Civil Engineers, referred to later on in this paper, gives full details of the tests and results.

Continuing the information respecting the methods of producing ferro-chromium, the following will probably be of service, as it embodies the latest and best practice.

It has been found that the reduction of chromium from its oxides is not so difficult as that of manganese from its oxides, that is, the simple deoxidation is less difficult, due probably to the affinity between the metal and oxygen being weaker. Notwithstanding this, the production of ferro-chromium of high percentages, such as 30 to 40 per cent., in the blast furnace, is more difficult than that of 80 to 84 per cent. ferro-manganese, and requires *much* more fuel. This seems to arise from the fact that the ferro-chromium requires considerably higher temperature for its fusion, and also through the practical necessity of allowing little or no oxide of chromium to get into the slag. It has been found that if the slag contained much oxide of chromium, or even as low as 5 per cent., the metal would not be sufficiently fluid to flow from the furnace. It has been suggested that the presence of the slag containing much oxide of chromium, in contact with the fused metal, tends to decarbonise or desiliconise it, and so to decrease its fusibility. This, indeed, is only surmise; but if correct, it shows that chromium resembles iron in its character rather than manganese. It appears to be a fact, however, that in order to obtain ferro-chromium thoroughly molten in character, large quantities of fuel must be used, and that the reduction of the oxide of chromium must be nearly or quite complete. In the case of ferro-manganese, and even with ordinary spiegel, the reduction of the oxide of manganese is never anything like complete;

more than 80 per cent. of the total of manganese in the ore is seldom obtained in the metal. Usually, however, oxide of manganese fluxes readily into the slag, whereas it is extremely difficult to flux oxide of chromium.

These differences in the character of the oxides of the two metals probably account for their differences of behaviour in many of the operations in which they are concerned. Mr. Holgate, a member of this Institute, who has done so much to perfect the reduction of ferro-alloys, informs the writer that some years ago he made a crucible experiment to arrive at the degree of the reducibility of Cr_2O_3 . He used a mixture of iron and manganese as well as iron and chrome ore, with carbon and flux, and found that practically all the iron and chromium were reduced, but in the other case only about two-thirds of the manganese was found.

Referring to blast furnace practice for the production of 40 per cent. ferro-chromium, it has been found that even more than three tons of coke per ton of ferro-chromium are required, and much experience is necessary before this higher percentage can be successfully produced. By experts it has been thought that, though ferro-chromium of the higher percentages can be made in the blast furnace, it is hardly probable that 60 per cent. will be reached—at any rate, not with the ordinary chrome iron ores. High percentages would also require very high temperatures of blast, say 1500° or 1600° F., so as to produce the necessary temperatures for fusion. It has also been pointed out that in chrome iron ores containing one equivalent of Cr_2O_3 and one of FeO , the theoretical limit would be 57 per cent. of chromium only, as the metal would probably not contain more than 90 per cent. of chromium and iron. The limit would no doubt be still lower than this, as the ash of the coke always contains some iron, and this would contribute to the raising of the total of elements other than chromium.

Ferro-chromium of 35 to 40 per cent., although very liquid when tapped, and possessing a far higher temperature when being run from the blast furnace than 80 to 84 per cent. ferro-manganese, solidifies very quickly. A proof of the high temperature is the fact that the moulding sand in the pig beds when in contact with the metal becomes pitted and almost fused—in fact, can only be separated with difficulty. In lower ferro-chromium, 10 to 20

per cent., these special characteristics are not so marked, either as regards difficulty of fusion or the amount of coke required. Slags containing chromium are usually yellowish-brown on the surface.

It has been stated that some of the ferro-chromium produced on the Continent is made by mixing a good quality of Bessemer slag with the chrome ore. Details of this are given in Appendix D.

CRYSTALLISATION OF FERRO-CHROMIUM.

Brustlein's ferro-chromium, of which he showed an excellent collection at the last Paris Exhibition, was very varied in crystallisation and percentage. It contained as high as 84 per cent. chromium, and some showed as high as 11 per cent. carbon. As regards the 40 to 70 per cent. specimens, those highest in chromium were not necessarily so as regards carbon; in fact, there seems to be no fixed rule as to how the proportion of the latter is regulated.

Some alloys of curious composition were exhibited, one sample with 48 per cent. chromium and 8 per cent. carbon having also 17 per cent. of silicon. This alloy is stated to have been specially brittle, though brittleness is more or less the characteristic of all ferro-chromium. Full analyses of the different productions of ferro-chromium are given in Table XIII.

As regards crystallisation, *low* chromium pig iron, if cooled quickly, has a slight resemblance to spiegeleisen. The higher percentages have a marked character of their own, either of acicular structure or having crystals with small facets. This is specially noticeable in certain qualities of ferro-chromium, and is probably to some extent regulated by the rate of cooling. The needle formation takes place very suddenly. M. Brustlein tells of a case where a part of the contents of the crucible having been accidentally upset on the floor of the furnace, this needle formation was very apparent during cooling. M. Vosmaer, in his book before referred to, says that the higher the carbon the more marked is the acicular structure.

Although ferro-chromium is brittle, to show how much this is owing to the high percentage of carbon usually present, M. Brustlein, referring to a 71 per cent. ferro-chromium, containing

only 3.45 per cent. carbon, stated it to be very decidedly less brittle than a similar material containing 6 to 7 per cent. carbon. Its fracture showed small facets, and was not acicular in structure. Moreover, it would not scratch glass. Here is a remarkable proof of an alloy containing 70 per cent. chromium being dependent upon its carbon contents for extreme hardness. It is a curious confirmation of the fact that in all steel and ferro alloys, carbon is essential to produce hardness. M. Brustlein also points out that the fracture of ferro-chromium differs rather according to its contents of carbon and silicon than to that of chromium. He says it is very difficult to determine at sight the proportion of the chromium present, and whether it is saturated with carbon or with carbon and silicon. When strongly charged with carbon or with carbon and silicon, it always has a tendency towards acicular structure, and is hard and brittle, but, as the proportions of these two metalloids diminish, the hardness and brittleness of the alloys grow less.

MAGNETIC PROPERTIES OF FERRO-CHROMIUM.

Various statements are made respecting the magnetic properties of ferro-chromium. The following observations by the writer were confirmed by Mr. Holgate, of the Darwen and Mostyn Company:—Ferro-chromium of 8 and 28 per cent. is readily attracted by the magnet; that containing 44 per cent. is only attracted slightly in bulk, but when in small pieces, or in a powdered state, the material is strongly affected; 66 per cent. is not attracted in bulk, but when in a powdered state it is attracted, though only slightly.

M. Brustlein has stated that 71 per cent. ferro-chromium, containing 3.45 per cent. carbon, is strongly attracted, but that he had observed that other samples containing similar percentages of chromium, but with higher carbon, were *not* sensibly affected. He considered that the amounts of carbon and silicon principally influenced the magnetic characteristics. As just named, the writer has found that 66 per cent. ferro-chromium, containing about 7 per cent. carbon, though not attracted when the material is in bulk, is slightly so if reduced to fine powder. Any observations, therefore, on the magnetic qualities of ferro-alloys should be accompanied by a statement as to the nature of the samples tested.

USE OF FERRO-CHROMIUM IN CAST IRON.

As regards the use of chromium as an addition to cast iron, there does not seem to be a probability of any large application. It confers hardness, not *per se*, but owing to the property it possesses of driving the carbon present into the combined form. It might be worth while to see whether an intermediate quality or percentage below that at which the chromium present retains the carbon in the combined form, would be of service for, say, chilled rolls and other special purposes. Certainly the extreme hardness it confers, if it could be properly controlled, would be useful. There may also be some intermediate point where, possibly by the addition of a small percentage, a useful increase in transverse strength would result, but the percentage must not be sufficient to cause all the carbon present to take the combined form, or the result would be a brittle material. The matter has not yet been investigated as it deserves, and it is not wise to make any general assertions in the absence of fuller evidence. Mr. Keep of Detroit, Mich., who has done so much good work in alloys of cast iron, may perhaps take up this question.

In ferro-chromium or chromium pig iron, the whole of the carbon present is in the combined form.

Molten chromium pig iron of low percentage does not scintillate like molten white iron of similar carbon contents; it runs "dead," notwithstanding the lowness or absence of silicon.

Attention is drawn to the specific gravities of the different chromium steels and ferro-chromiums. The higher percentages of the latter give somewhat lower results than would have been expected, seeing that the specific gravity of the metal is stated as being 7.7.

Before proceeding to describe the results of the writer's experiments, the following list, showing the tables and diagrams referred to in this paper, may be of service:—

*Statement Showing the Tables and Diagrams used to Illustrate
the Paper.*

Tables.	Diagrams.	
I.	I.	General table and diagram of the different tests and analyses of the chromium steel described in the paper.
II.	II.	Comparison of elastic limit, tensility, elongation, and bending tests between chromium, silicon, and aluminium steels.
III.		Bending tests of cast and forged chromium steel.
IV.	III.	Compression tests of chromium steel.
	IV.	Comparison of compression tests between chromium, silicon, and aluminium steels.
V.	V.	Comparative hardness of chromium, silicon, and aluminium steels.
VI.	VI.	Dr. Hopkinson's ring experiment.
VII.		Chromium steel-wire test.
VIII.		Water-quenching tests.
IX.		Thermal treatment of chromium steel.
X.		Welding tests of chromium steel.
XI.		Specific gravities of chromium steel and ferro-chromium.
XII.		Melting-points of do. do.
XIII.		Analyses of ferro-chromium.
XIV.		Tests of chromium steel by Messrs. Holtzer and others.
XV.		Tests by Messrs. J. Shipman & Co.
XVI.		Corrosion experiments.

MANUFACTURE OF THE CHROMIUM STEEL SAMPLES DESCRIBED
IN THIS PAPER.

The material used as a basis was good wrought iron scrap showing small percentages of sulphur and phosphorus. To this was added varying quantities of ferro-chromium containing about 6 per cent. of carbon and 66 per cent. of chromium. The melting operations were carried out in ordinary clay crucibles as used in the Sheffield steel manufacture. The ingots and bending strips were poured in the usual manner. The former were $2\frac{1}{2}$ inches square, and were afterwards reduced by cogging and rolling to bars $1\frac{1}{2}$ inch diameter.

The manufacture of these alloys was not easy, owing to the refractory nature of the rich ferro-chromium. The writer has seen pieces of rich ferro-chromium come out of the crucibles unmelted, though subjected to several hours of the most intense heat of a Sheffield crucible furnace. If the temperature is allowed to diminish even for a short time, the contents of the crucible are

liable to become solidified. No doubt with care and practice this can be avoided, but it is a considerable difficulty. The contents of the crucible require repeated stirring to ensure thorough mixture, and great care has to be taken to prevent any lowering of the temperature during this operation. As is also proved by M. Osmond's experiments (see Table XII.), there is considerable difficulty in fusing rich ferro-chromium.

When the melting operation is carefully carried out, and the heat properly maintained, the pouring possesses no special difficulty; in fact, the product is as fluid as other alloy steels, but cools rapidly—much more so than carbon steel. As it is probable that chromium melts at a higher temperature than iron, this difference might be expected.

SOUNDNESS.

One point has been clearly proved—that chromium in steel does not confer soundness, and in this respect its action differs from that of either silicon or aluminium. Reference is here made to malleable chromium alloys, as chromium pig irons, or at any rate those of lower percentages and in which the carbon is high, are very sound and free from honeycombs. The writer has made steel containing as much as 1.35 per cent. chromium (.28 per cent. carbon), which "rose" badly in the moulds. Therefore, at any rate in these malleable compounds, it is necessary to add a certain percentage of silicon or aluminium, or both. Aluminium does not seem to act so powerfully as in carbon steels (the writer here is specially referring to *low* carbon-chromium steels), and a larger percentage seems requisite to produce soundness. It is difficult to state the highest percentage of chromium which may be present without conferring soundness, owing to the fact that, as the chromium increases in the samples now described, so does the carbon, thus obscuring the deductions. Probably even 3 or 4 per cent. chromium would not confer freedom from honeycombs; therefore it is hardly to be expected that a satisfactory and perfectly pure chromium and iron malleable alloy will be obtained. However, the comparatively small percentages of aluminium and silicon required do not materially affect the product, as will be

seen from the mechanical tests. In fact, owing to an error, the samples "A" to "G" were made with double the quantity of aluminium intended, about 40 per cent. instead of 20 per cent. It is probable that this larger amount had little or no influence upon the tensility and ductility of the specimens. The slight effect of small quantities of aluminium upon the mechanical properties of iron has been fully proved in the writer's paper on aluminium steel. The additions of aluminium were not continued beyond sample "G," the carbon and silicon present being then sufficiently high to render this unnecessary.

The further description of the different products branches into two classes, viz. :—

A. Chromium steel in its cast state.

B. Chromium steel in its forged state.

A. Cast State.—As will be seen from Table I., samples have been obtained containing as high as 16.74 per cent. chromium ("O"), but this material is only partially malleable. Probably this is owing to the carbon (2.12 per cent.) being so high. Specimen "N" (15.12 per cent. Cr) was, by very careful treatment, sufficiently malleable to obtain test bars, but this is about the limit of forgeability, at any rate in the presence of the unavoidable amount of carbon (1.79 per cent.). If it were possible to obtain a carbonless, or nearly so, chromium steel, no doubt forgeability would continue to as high a point as in manganese steel (22 per cent. Mn).

The fractures from the unannealed ingots show no special structure, as in manganese, silicon, and aluminium steels, when about 4 per cent. of those elements was reached in their respective alloys. Samples "A," "B," "C," and "D" possess an open coarse grain—even annealing, which was carried out in the usual way, but perhaps not to a sufficiently high temperature, seeing the low percentage of carbon present produced but little effect.

Sample "E" (12 per cent. C. and 8.4 per cent. Cr) showed a slight alteration, the crystals being somewhat finer. Further changes then gradually took place, and when sample "I" was reached (4.1 per cent. C., 3.17 per cent. Cr), it gave a "hard steel" fracture, similar to that of good 0.75 per cent. carbon steel. This, by

annealing, was changed into a close fine-grain structure. It would appear, therefore, that chromium, at any rate up to 1.50 or 2 per cent., when carbon is absent, or present in small quantities, has but little or no influence upon the crystallisation of the iron present. This refers to cast specimens; the forged samples behave in a slightly different manner, the change in the size of the crystals occurring with a somewhat lower percentage of chromium. This characteristic, as regards the cast specimens, was noticed not only in the fractures from the sections of the $2\frac{1}{2}$ -inch square ingots, but in those from the cast bending pieces, which were not more than 1 inch wide by $\frac{5}{16}$ inch thick.

It would appear—and this is important to bear in mind when considering the crystallisation of this steel—that so long as the carbon is about .30 per cent. and under, the effect of chromium upon the crystallisation of iron is only small, but when the carbon is present in higher percentages, its action is different. The chromium then acts much more energetically, or perhaps one should say, it enables the carbon present to act more energetically upon, and to combine more readily and intimately with, the iron. It is an interesting point to decide whether chromium *per se* has much influence upon iron (that is, carbonless iron). Judging from the writer's tests, its action seems but little greater than that of silicon or aluminium.

The exact rôle played by a third element in an alloy or mixture such as steel is a complex one. It is one of those metallurgical puzzles in which the help of the Wise Men of the East would be very useful.

As showing the powerful influence of carbon, and that chromium is not in itself a hardener to the degree often supposed (this has been naturally so, seeing that chromium is believed to be an exceedingly hard metal), M. Brustlein mentions the case of a 71 per cent. ferro-chromium with 3.41 per cent. carbon, which was less hard and brittle than a similar metal containing 6 per cent. carbon. In the face of this fact, it would be interesting to know whether pure chromium is really the hard metal described in the text-books. All the samples of so-called chromium metal examined by the writer have been found to contain carbon. A more careful examination by the physicist of the metal's true

properties would prove useful. This lack of precise knowledge applies to many of the elements, and it seems a defect in scientific knowledge to have doubts upon such points. Not a few of our data as to the exact characteristics of several of the important metallic elements seem to be based upon results and experiments undertaken when both knowledge and scientific apparatus were in a very crude condition.

Samples "J," "K," "L," and "M" (5 per cent. to 15 per cent. Cr.) behave in a somewhat similar manner to "I," but "N" and "O"

$$\frac{(1.79 \% \text{ C. and } 15.12 \% \text{ Cr.})}{\text{"N"}} - \frac{(2.12 \% \text{ C. and } 16.74 \% \text{ Cr.})}{\text{"O"}}$$

show but little change by annealing. Before this treatment they are hard, and seem to possess somewhat of the nature of badly chilled cast iron. The percentage of carbon being so high, they ("N" and "O") behave more like "cast iron," a species of which they really are, being non-malleable and of but little cohesive strength.

When breaking off the tops of the unannealed ingots, similar characteristics are observed regarding the point at which the marked changes in structure and strength take place. Samples "A" to "G" did not vary much in their toughness, each standing about 20 blows with a 16-lb. sledge-hammer, and requiring one blow of a steam-hammer before fracture resulted. But after this the toughness rapidly diminished; samples "J" and upwards requiring but one blow each to cause fracture. The exact degree of toughness possessed by the respective samples is better and clearly shown in Table III., which gives the results of bending tests upon annealed and unannealed cast and forged samples. Each test bar was 1 inch broad by $\frac{5}{16}$ inch thick.

Annealed cast samples "A" to "D" bent double cold. "E" and "F" bent 77° and 76° respectively; probably these were less owing to slight flaws, as "G" bent double cold. Here again the dividing line between the tough and somewhat brittle cast specimens seems to be "G" (21 per cent. C. and 1.51 per cent. Cr.), which is the highest chromium alloy of those samples in which the carbon is under .25 per cent. This seems to clearly indicate that the rapid diminution in ductility in samples "H" and upwards is owing to the increase of carbon rather than to that of chromium.

Samples "H" and "I" show a small amount of toughness, but "J" to "N" have practically none, being exceedingly brittle.

HARDNESS.

Both annealed and unannealed samples up to "H" are easily filed. After this hardness rapidly increases, annealing but slightly modifying this property. Samples "L" and upwards are exceedingly hard, and could scarcely be touched with the best file.

Steel similar to sample "L" (.71 per cent. C., 9.18 per cent. Cr.), but *without* chromium, could be easily filed in its unannealed state, that is, as a carbon steel, with not more than .78 per cent. C. It is also safe to say, that if the carbon in sample "I" were not more than .25 per cent., the chromium remaining the same, that is, 9.18 per cent., this steel would also be easily filed. It is, therefore, clear that carbon plus chromium, or chromium plus carbon, whichever way we look at it, give quite a different product in an iron alloy, or, as M. Osmond suggests, there is probably a definite compound of chromium, iron, and carbon, partially dissolved and partially isolated, according to the percentages present. We know that .75 per cent. carbon steel would harden energetically in water, therefore it seems that chromium acts as a sort of spur to the carbon, or favours the formation of the hardening form of carbide of iron, and even without the intervention of the ordinary cooling medium, water. M. Osmond, to whose services the metallurgical world owes a large debt of gratitude, has so fully investigated this question for the writer, and in his usual thorough manner, that it is unnecessary to deal with the matter more fully here. His results and suggestions will be found added as a report to this paper.

Professor Turner of Birmingham has, with his sclerometer, kindly made for the writer a set of tests as to the hardness of these chromium samples (Table V.). This apparatus might with advantage be employed more widely in metallurgical operations, enabling comparisons to be much more readily drawn between various products. Professor Turner having also determined the hardness of the author's specimens of silicon and aluminium steels, this third comparison, chromium steel, is specially interesting.

Owing to increased wear and tear, higher speeds of machinery,

and other high-pressure factors of modern industries, the question of relative hardness, as bearing upon the question of increased durability, is most important; therefore it is to be hoped Professor Turner will continue his valuable work in this direction.

We are now, thanks to M. H. le Chatelier, and to Professor Roberts-Austen in this country, able to indicate with a definite degree of accuracy the highest temperatures of metallurgical operations, instead of, as formerly, using the vague terms cherry red, high yellow, or other indefinite descriptions of heat. These terms, whilst useful enough for many purposes, are often misleading, owing to the different judgment of different observers.

Is it, therefore, too much to expect that determinations of degrees of hardness should also be approached in a systematic way? Professor Turner has put within our reach a valuable apparatus, and perhaps the Mechanical Engineers' "Alloys Research Committee" might add an examination of this question to their programme.

Professor Turner's tests on the chromium steel samples are described in Table V. and Diagram V., and in the latter a comparison is plotted between chromium, aluminium, and silicon steels, in which their similar effect upon iron, as regards hardness, is brought out very clearly.

From the diagram it is fully confirmed that chromium *per se* does not appreciably harden iron, for sample "H," containing 2.54 per cent. chromium, is no harder than silicon or aluminium steel of similar percentage in their respective elements. In fact, they differ but little from the mild steel and wrought iron tested by Professor Turner. This result is a remarkable confirmation of the comparatively neutral effect of chromium upon iron. Thus it is clear that the much greater hardness of samples "J," "K," and "L," is owing to the higher percentage of carbon they contain, and not *per se* to the chromium present.

The apparent discrepancy in sample "J" is explained by the fact that Professor Turner's assistant, finding the sample harder than expected, heated and annealed it in ashes. This, for the reasons stated by M. Osmond in his report on the thermal treatment of the different samples, contributed to increase rather than decrease its hardness.

The statement that chromium does not materially harden iron is not in itself new, as M. Brustlein and M. Boussingault have before stated that carbonless, or nearly so, chromium steel did not harden when water-quenched; but the manner of proving it so conclusively has probably not before been presented.

M. G. Rolland in the *Annales de Chimie* for 1877 (vol. xiii. p. 152) also stated that chromium would not take the place of carbon or hardened steel.

It is noteworthy that whilst chromium, so far as we imperfectly know its properties, is a hard metal, yet its addition in the absence of carbon does not produce any greater hardness, at any rate up to 3 or 4 per cent., than steels of similar silicon and aluminium percentages. Chromium, therefore, in its effects upon iron *as regards hardness*, may appropriately be classed along with most of the other non-hardening elements alloyed with that metal. Probably carbon must still be considered to be the only true hardener of iron. Even manganese, whilst giving great increase in natural hardness, does not confer that particular quality that will compare with the hardness of water-quenched carbon steel.*

In view of the interesting research work done by Professor Roberts-Austen as to the effect produced by elements of certain atomic volume when alloyed with iron, it may be pointed out that the atomic volume of chromium is 7.70, and of manganese 6.90, iron being 7.20. Thus chromium comes in position amongst that class of elements which, Professor Roberts-Austen believes, do not harden iron, whilst manganese, being below the atomic volume of iron, is in that class which are believed to harden iron. Certainly a 4 per cent. forged manganese steel, when cooled quickly in air, is brittle and hard, whilst a 4 per cent. chromium steel, provided the carbon is low, is comparatively soft. This is an interesting confirmation of Professor Roberts-Austen's theory, though it must not be forgotten that a 12 per cent. manganese steel behaves in a different manner.

B. Forged State.—The ingots were fairly clean and free from

* This remark may require some modification. M. Osmond is now investigating the peculiar properties possessed by samples of manganese steel made some time ago in the writer's experiments on alloys of iron and manganese; that is, the hard and brittle 4 to 5 per cent. alloy, and in which the carbon is under .35 per cent. But in any case, even this alloy does not possess the same qualities as hardened carbon steel.

slag. No special care was taken in their treatment except as regards the harder products. Samples "A" to "F" were reported as working similarly to ordinary mild steel. Ingot "G" worked a little harder, but no trouble was experienced with any of the samples up to "M." "N" cracked badly, but sufficient material was obtained to make a test-bar. Ingot "O" (2.12 per cent. C. and 16.74 per cent. Cr.) would not, however, either forge at a medium or low heat, and sample "M" may be taken as the highest limit of forgeability. Should it be found possible to reduce the carbon, then with care probably higher percentages would be forgeable.

From each sample forged bending strips $4\frac{1}{2}$ inches long, by $\frac{11}{16}$ inch wide, by $\frac{1}{8}$ inch thick, were prepared. Table III. gives the results of these tests.

Samples "A" to "G," both in the unannealed and annealed condition, bent double cold.

In samples "H," "I," "J," "K," and "L" are observed curious results, for it is found that whilst the annealed samples bent double unbroken, with the exception of "L," which bent double but broke, the unannealed samples bent *nil*. Such a marked difference, leading to a closer examination, showed that the sample bars, being of thin section, $\frac{1}{8}$ inch thick, had become hammer-hardened: in fact, they were almost as hard as if water-quenched, clearly showing that in these smaller sections, when larger percentages of chromium and not less than .35 per cent. of carbon are present, quick cooling is followed by a considerable hardening. Steel with the same percentages of chromium without carbon could not have been hardened, or but superficially, by the most rapid cooling in water, and much less could hardening have been caused by mere contact with the forging dies or hammer faces.

As regards the mechanical tests, tensile and compression, these are fully given in Tables II., III., and IV., and Diagrams II., III., and IV. The tensile bars being of the same dimensions as those described in the writer's papers on silicon and aluminium steels, comparison can be readily made. The elongations were measured on a length of 2 inches,* and upon an area of .50 square inch.

* The following, obtained from the results of a considerable number of Admiralty tests, may be of service when comparing elongations on different lengths:—

Elongation per cent. on 2 inches	× .75 = elongation on 8 inches.
Do. do.	8 do. × 1.32
	do. 2 do.

This short length, of course, gives higher elongations than with 4 inches or 8 inches, but the previous tests with silicon and aluminium steels having been with 2-inch lengths, it was thought best to adhere to this. A Whitworth testing-machine was used, and special care was taken in obtaining the records of the permanent set or elastic limit, each bar in the case of the harder samples being taken out of the machine and measured in a Whitworth measuring apparatus, after each successive increment of two tons of stress, so that the slightest permanent stretch, if any, at such stress was detected and the yield-point accurately obtained. As a matter of fact, in the Whitworth machine the "give" of a test-bar is so readily apparent on the indicating dial that no special precautions are necessary, at any rate up to stresses of 25 tons per square inch. The writer was, however, specially desirous to see if chromium *per se*, and in the presence of small percentages of carbon, does really raise the elastic limit so much as is believed. It will be seen that it does not do so in the *annealed* samples, as, with the exception of "H," there is no real elastic limit higher than 20 tons per square inch. Probably with accurate handling this would be found to be the case with most hard steels when annealed, and it is questionable whether the high elastic limit in samples unannealed or partially hardened by rolling or forging is of any real service. Such a condition seems to a great extent to be a strained or partially hardened condition of the outer layers of the material.

These remarks do not refer to samples hardened in water or oil, or by other quick cooling. Here the action is so much intensified that a different set of circumstances arises; probably there is also a chemical change in the material, involving an entire rearrangement of molecular structure. This interesting question will be found subsequently dealt with at greater length.

FRACTURES FROM BARS.

From each of the rolled bars of $1\frac{1}{2}$ inches diameter, from which the tensile pieces were prepared, small samples were broken. Specimens "A" to "G" were difficult to break, the bars requiring nicking, and giving somewhat characteristic fractures. They were

of dark fibrous nature, and almost black in appearance. Sample "H" (39 per cent. C., 2.54 per cent. Cr.) was the first to break with a crystalline fracture, and had the appearance of ordinary mild steel. A rapid change then occurred, the fractures being hard, and of fine crystalline structure. With the higher percentages the structure was almost porcelainic.

TENSILE TESTS.

The tensile tests gave interesting results. These are fully shown in Tables I. and II., and in Diagrams I. and II.

Table I. gives a complete record of the tests, including analyses, specific gravity, mechanical tests—both tensile and bending—welding and hardness tests. Diagram I., plotted from this table, gives graphically the mechanical tests. At the foot of this is also plotted the percentage of carbon and chromium, so that, with the plotting of the mechanical tests immediately above, comparison is readily available. The curves are fairly regular, with one or two exceptions, which are unavoidable in experimental work of this kind.

Table II. and Diagram II. give comparisons of tensile tests between forged chromium, silicon, and aluminium steels. It will be noticed, up to a certain point, how closely these tests resemble each other. As regards the sample with 5.19 per cent. chromium, its behaviour must naturally be expected to differ, owing to the carbon being so high—.77 per cent.—as compared with the lowness of carbon in the silicon and aluminium samples. The first three comparison samples up to $1\frac{1}{2}$ per cent. show how slightly different is the effect produced upon carbonless (or nearly so) iron by the addition of similar amounts, respectively, of chromium, silicon, and aluminium.

Although chromium steel is generally credited with being a hard material, it will be seen that if the carbon present is low, its hardness and stiffness is but slight. In the four samples "A" to "D" (22 to 57 per cent. Cr.) any increase of tensile strength between the unannealed and annealed samples may be set down rather to slight hammer-hardening than to any real difference in tensility.

It is important to prove by mechanical tests, as these now do, that chromium *per se* does not harden iron. It shows that another aspiring competitor is out of the race with carbon. In the writer's papers to this Institute this has already been proved to be so as regards aluminium and silicon steels.

Practically speaking, chromium steel samples "A," "B," "C," and "D" do not materially differ from the first four aluminium and silicon steel samples; in fact, in comparing the three sets it will be found that silicon steel has, though the difference is comparatively small, the highest tensility, aluminium the lowest, and chromium is midway between the two.

The chromium tests seem to divide themselves into groups—"A" to "G" (.22 to 1.51 per cent. Cr.), "H" to "L" (2.54 to 9.18 per cent. Cr.), "M" and "N" (11.13 and 15.12 per cent. Cr.).

It may be stated that some of the tests in the higher percentage material having given apparently anomalous results, repeat analyses were made from the test-bars themselves. In no case was any cross-marking of samples found to have occurred, so that the results shown may be taken as reliable.

"A" to "E," in which the carbon is low, under .20 per cent., vary but little in either tensility, ductility, or elastic limit. In these samples annealing causes a slight lowering of the tensility and elastic limit, and raises the ductility.

At "F" a marked change takes place, showing how sensitive is the steel to the action of carbon, which has increased from about .15 to .25 per cent. The tensility increases by some 8 or 9 tons, and the elastic limit also rises considerably.

From this point the region of hard steel is reached; the maximum apparently is "M," both for the unannealed and annealed samples. Specimen "J," with a tensility of 74 tons per square inch, is reduced by annealing to 55 tons.

The pronounced action of annealing is clearly shown by the great reduction it produces in the elastic limit. Here again, one may say, when speaking of unquenched steel, high elastic limits probably show a strained and artificial condition of material which annealing removes. Indeed, we may imagine that hardened steel (that is, water or oil hardened) is a material in which the mole-

cules are in a state of intense strain, often relieved, in the case of hardened steel projectiles, by the material spontaneously rupturing itself. It appears, therefore, that any material to be used, where subjected to sudden and intense strains, should not be in the condition of having a high elastic limit. If heavy guns were made of a grade of steel having medium tensility, but with a disregard to high elastic limit, it is probable that less failures would occur—in other words, that it might be found better to have a harder grade of steel with a lower and natural elastic limit ("primitive elastic limit," as Mr. Kreuzpointner terms it) than a milder steel in which a higher elastic limit is obtained by means of sudden cooling, and which is probably a "strained" elastic limit.

Mr. Kreuzpointner, of the Pennsylvania Railroad, Altoona, Pa., U.S.A. (*Iron Age*, 19th March 1891), in an excellent paper respecting testing materials, points out that, in his opinion, more importance than is ordinarily imagined should be attached to the determination of the elastic limit in iron and steel. He states that in a tyre, for instance, it is by no means a matter of indifference whether the required elastic limit be obtained by cold rolling or by chemical constituents. The uncertainties as to the elastic limit of metals can be largely lessened by annealing and carefully cooling. He considers that Krupp has highly benefited by a thorough understanding of the corrective influence of annealing and slow cooling. The nearer the elastic limit of a given product to the primitive elastic limit when it leaves the mill, the safer will be the position of the manufacturer, other things being equal, as to the final outcome of that material in subsequent service; whilst, if the product departs from such primitive elasticity, the more risk, because of the changes liable to take place in the material under the influence of forces which would not change the metal within its primitive elastic limit.

The writer refers to these opinions somewhat fully, believing that many of the "mysterious" failures that occur with steel—happily they become less and less frequent—have arisen through disregard of the principles pointed out by Mr. Kreuzpointner.

That chromium steel is a material essentially liable to structural

changes by thermal treatment such as annealing, is clearly seen by the results of the tests given in Table IX.

As in other steel, annealing very largely reduces both the tensility and elastic limit. As will be seen from some of the tests, particularly those of the harder ones, annealing, as Mr. Kreutzpointner says, has a tendency to put the metal upon its merits; in fact, to destroy any artificial hardness and to restore the equilibrium. It is for this reason that the water or oil hardening of large masses of steel, whilst good for certain purposes, requires most careful attention, so that the strains produced may be balanced or neutralised in such a manner as not to cause the objections so pertinently stated by the American engineer named.

In comparing the tensile and bending tests (Table II.) of chromium, silicon, and aluminium steels, the special difference between the effect of chromium and the other alloys is clearly brought out by chromium steel sample "J" (5.19 per cent. Cr.). The forged specimen from this bent double cold, notwithstanding its comparatively high percentage of carbon (.77 per cent.), whilst the silicon steel (5.53 per cent. Si.) would not bend at all, and the aluminium sample (5.60 per cent. Al.) only bent 16° before breaking. In both the latter cases the carbon was very low (.26 per cent. and .22 per cent. respectively). Thus it is clear that, as regards material in the forged and annealed condition, much higher percentages of chromium may be combined with iron before brittleness occurs, as compared with the two other elements.

There is, however, not such a marked difference between the chromium and aluminium steels in their cast states. The former is certainly tougher, but the same sample "J" (5.19 per cent. Cr.), which bent double cold in its annealed forged condition, will not bend more than 3° in its annealed cast state; therefore in this respect it has but little superiority over aluminium sample "J" (5.60 per cent. Al.), which also showed no bending properties. Silicon steel becomes brittle at a much lower percentage.

COMPRESSION TESTS.

Table IV. and Diagram III. give the results of the compression tests, and Diagram IV. shows the comparison of compression tests between chromium, silicon, and aluminium steels.

The chromium steel samples "A" to "G" (.22 to 1.51 per cent Cr.) give practically the same resistance to compression as the silicon and aluminium steels. Sample "H" (2.54 per cent. Cr.), under a compressive load of 100 tons per square inch, shortened about 10 per cent. less than the silicon and aluminium steels of corresponding percentages; but in the case of the chromium steel it must be borne in mind that the percentage of carbon present was twice as much, so that any increased resistance must be attributed to the effect of the latter. Samples "J," "K," and "M" (5.19 to 11.13 per cent. Cr.) showed high resistance to compression, but again it must be borne in mind that the carbon present was considerable, viz., .77 to 1.27 per cent.

Provided a suitable amount of carbon is present, no doubt chromium steel will resist a higher compression stress than ordinary steel.

It is specially noticeable that these chromium compression test-pieces do not show the rough ribbed appearance on the outside, as was the case with the aluminium and silicon compression samples.

WATER-QUENCHING TESTS.

In Table VIII. will be found results of water-quenching upon the different chromium steel samples. The effect of different temperatures is clearly brought out in the bending and filing tests, and it is interesting to again find a confirmation of the non-hardening qualities of chromium steel low in carbon. Samples "A" to "G," in none of which the carbon exceeds .25 per cent., are not hardened, even when quenched from the highest heats. The bars being only one-eighth of an inch thick, and the cooling action consequently very rapid, the slightest tendency to harden, if it had existed, would have been immediately apparent.

THERMAL TREATMENT.

Table IX. shows the effect of quickly cooling chromium steel in air. These tests brought out the interesting fact that steel containing high percentages of chromium and sufficient carbon, for example, sample "J" (.77 per cent. C., 5.19 per cent. Cr.), possesses self-hardening properties. This is probably the first

time that this fact has been put on record. Hitherto it has been thought that carbon steel containing tungsten only, or tungsten combined with chromium, possessed this quality. M. Osmond, in his report, deals with this interesting fact at considerable length.

WELDING TESTS.

Table X. proves that chromium is not favourable to welding. Probably the experiment with "B" (·16 per cent. C., ·29 per cent. Cr.) was not carried out under the best conditions, but it was also found by M. Brustlein, at any rate when the chromium exceeds a comparatively small amount, that the welding properties are interfered with. It might, of course, be possible to fuse *fluid* chromium steel to wrought iron or steel, but the ordinary process of welding together two bars is not possible either with this alloy, or with those previously experimented upon by the writer, viz., manganese, silicon, and aluminium steels.

In Table XVI. will be found the results of the corrosion tests. Each sample, $2\frac{1}{2}'' \times \frac{1}{2}'' \times \frac{1}{4}''$, was immersed for twenty-one days in H_2SO_4 of 50 per cent. strength. The samples "F" (1·18 per cent. Cr.), "J" (5·19 per cent. Cr.), "L" (9·18 per cent. Cr.), showed a loss of 3·32 per cent., 4·78 per cent., and 5·64 per cent., respectively. Ordinary mild steel, tested under the same conditions, lost 7·48 per cent., and wrought iron 4·47 per cent.

TABLE XVI.—Corrosion Experiments.

		Percentage of		Strength of Acid (H_2SO_4),	Length of Immersion.	Loss per Cent.	Colour after Treatment.
		C.	Cr.				
				Per Cent.	Days.		
Chromium steel, (F)	Bar	·27	1·18	50	21	3·32	Bright appearance in some parts.
"	" (J)	·77	5·19	"	"	4·78	Tarnished, no bright appearance.
"	" (L)	·71	9·18	"	"	5·64	Dull and tarnished.
Silicon steel (E)	"	·20	2·67	"	"	3·32	Very bright appearance.
Ordinary mild steel	"	...	...	"	"	7·48	Dull bright.
Wrought iron	"	...	...	"	"	4·47	Most brilliant.

GENERAL APPLICATION OF CHROMIUM TO STEEL MANUFACTURE.

Except for special classes of work, it is difficult to see the foundation for the exaggerated advantages that have been put forward by some for the employment of chromium. It is an open secret that certain works get good results with it, but other works, producing similar articles, and not using chromium, also have their products passed under the same specification without trouble.

It hardly seems probable, therefore, that this steel will, at any rate for some time, come into more general use, or displace ordinary carbon steel, except, as before named, in special work.

It may be well to state what has been previously done as regards chromium steel, though this reference must be brief.

One of the first workers in Europe to thoroughly investigate its manufacture on a practical scale was M. Brustlein, of Messrs. Holtzer & Co.—about 1876—whose productions have been principally in war material, such as armour-piercing shells, special armour or shield plates, tool steel, and some other uses.

The writer's father, about the same date (1876) as M. Brustlein commenced his work, was also engaged in chromium experiments, the ferro-chromium used having come from M. Biermann of Hanover, who was at that time, and has since been, instrumental in bringing special ferro-alloys before steel manufacturers.

M. Brustlein obtained results considered remarkable at that time, and exhibited samples of his products at the Paris Exhibition in 1878.

The Terre-Noire Co. also showed samples of ferro-chromium and chromium steel at the same Exhibition. Some years after, several French works followed M. Brustlein's practice, and the manufacture of chromium steel was considerably extended, owing to the large requirements of war material by the French Government.

In 1882, the writer's firm supplied chromium shells to the English Government, one of which, a 6-inch, successfully penetrated an 8-inch wrought iron plate, and was so little injured that it could have been fired again; also about the same time a 9.2-inch projectile, which penetrated a 16½-inch wrought iron plate and 8½ inches into a second plate placed behind. The same firm has since

been successful in passing considerable numbers into the English service. A short resumé of their latest tests may be of interest. By kind permission of the War Office, the results are illustrated by photographs of the plates and projectiles used.

Although principally makers of smaller calibres, as regards "armour-piercers," one of these experimental shells, 13·5 inches, weighing 1120 lbs., fired from the 63-ton breech-loading gun at a velocity of 1950 feet per second, penetrated an 18-inch compound plate, a 6-inch wrought iron plate, 20 feet of oak backing, a further 10½-inch wrought iron plate, and was then found broken beyond a 2-inch wrought iron plate—that is, a total penetration of 36½ inches of armour plating. This projectile was believed by the Ordnance Committee to pass *whole* through the 18-inch compound and 6-inch wrought iron plates. Fig. 3 shows the penetration effected.

One of their reception lots, viz., 300 6-inch projectiles, from which two were selected by the Government Inspector, gave the following results (Figs. 4 to 8 show the results of the tests).

Each shell was fired against a separate 9-inch compound armour plate, with a striking velocity of 1825 feet per second, and a striking energy of 2250 tons. The faces of these plates contained 1·25 per cent. of carbon, so that the tests were severe.

No. 1 projectile (round 2553, Figs. 4, 5, and 8) penetrated the plate to the eighth layer of oak backing. It was whole, showed no cracks, and very slightly altered in shape.

Diameter of body before firing, 5·963 inches ; after firing, 5·974 inches = + ·011 inches.
Length before firing, 16·68 inches ; after firing, 16·47 inches . . . = - ·210 inches.

No. 2 projectile (round 2554, Figs. 6, 7, and 8) gave the same penetration, was also whole, showed no cracks, and altered in diameter of body ·013 inches, and shortened ·210 inches.

Thus the above shells were only altered one-hundredth of an inch in diameter, and a little over two-tenths in length. (Figs. 4 to 8.)

The following results are, however, probably still more remarkable. A Hadfield 6-inch projectile was fired through a 9-inch compound plate. Being uninjured, it was ground up, fired a second time, and again penetrated another 9-inch compound plate. It was ground up and fired a third time at a 9-inch plate, when it

broke up. It is, however, only fair to the projectile to state that the third plate was an experimental one, in which the face had been hardened by special tempering methods. Probably the projectile would still have been whole if fired at an ordinary compound plate. This projectile, after being fired twice, is shown in Fig. 9.

Another remarkable result is that of a 6-inch bursting shell made by the same makers. This shell was the usual service weight, 100 lbs., but had a core of about double the capacity of an ordinary armour-piercing projectile (the latter are usually termed "shot"), and consequently its walls were of much thinner section and of less strength. This was fired at a 6-inch compound plate, which it penetrated, and was found uninjured 2000 yards (or nearly a mile and a quarter) on the other side. Beyond a slight chip off the point, the shell was unaltered in form, free from cracks, and could have been fired again. This shell is indicated by Fig. 10. The broken shell (Fig. 10^a) subjected to the same test was by another maker. The result with the latter shows that a steel shell, if not properly prepared, is little better than a cast iron projectile.

An exceptionally severe set of trials is that shown in Figs. 11 to 13. The projectiles were selected at random from ordinary service supplies. The ordinary reception trial is to fire a 6-inch projectile against a 9-inch compound plate, but in this trial the compound plate was $10\frac{1}{2}$ inches thick. As will be seen, notwithstanding the severe test, the four projectiles were practically uninjured, having neither set up nor broken. If the armour had been attached to the side of an ironclad, a few feet higher velocity would have resulted in a complete penetration into the interior of the ship. In other words, at short ranges, with the comparatively light 6-inch breech-loading gun, giving a velocity of say 2000 feet per second, all, excepting the largest modern ironclads, are easily vulnerable at point-blank range. (Figs. 11 to 13.)

In recent American trials it is reported that French-made projectiles, of 6 inches diameter, fired against $10\frac{1}{2}$ -inch nickel steel plates, penetrated from 9.70 inches to 26 inches, the average penetration being 15 inches. In the case of the Hadfield projectile, fired against a $10\frac{1}{2}$ -inch compound plate, the penetrations averaged

26½ inches. It must be remembered that in the American trials, while the nickel steel plates offered greater resistance, the velocity and striking energy, 2075 feet and 2989 foot-tons, respectively, were much higher than those used in the English tests, viz., 1830 feet and 2200 foot-tons. Therefore, whilst the results cannot very well be compared, it will be seen that the English projectiles, with a lower velocity and striking energy, gave excellent results. Probably with the same striking energy as at the Annapolis tests they would have penetrated uninjured a 12-inch compound plate.

As regards the percentage of chromium used in such shells, each maker has his own standard, the chromium varying from 1½ per cent. up to 2 per cent., and the carbon is dosed according to the particular hardness required.

Whilst Messrs. T. Firth & Sons have supplied considerable numbers of excellent armour-piercing projectiles, made under the French system of Firminy, the writer is sure they will not begrudge his firm (the Hadfield Steel Foundry Company) the satisfaction of having also successfully worked out this difficult manufacture, but without any outside or French assistance.

If any would-be aspirant to shell-making is under the impression that the manufacture of such articles is simply the result of producing steel of a definite analysis, he will find that this is not so. The quality of the material is not the only question, as care in manufacture during the subsequent treatment of hardening and tempering is most important.

M. Brustlein, in "The Metals at the Paris International Exhibition of 1878," stated that his attention was directed to chromium steel on account of its increasing both tensility and elastic limit without diminishing elongation, as would occur in carbon steel. In carbon steel an increase of tensility invariably means a decrease in ductility.

With the further knowledge gained from the study of the steel alloys named in this paper, it will be seen that chromium cannot itself confer much advantage when the carbon is low; in fact, its action in such cases may be to some extent termed neutral; but when the carbon also rises, the result is as stated by M. Brustlein. This metallurgist considers that beneficial results are obtained rather in harder than in milder chromium steels, and probably

this will be found to be the case. In other words, it must not be expected that very soft steel will be much improved by chromium additions. Medium steel probably will gain somewhat, and harder steels still more so; but, as is well known, the output of hard steel is comparatively small. For this reason, therefore, there does not seem the probability of a large employment of chromium in steel with a tensility of, say, 28 tons and under.

Chromium steel (that is, chromium-carbon steel) has another property—and reference is here again made to the harder qualities—that it seems to harden more readily. Chromium to some extent plays the part of a hardener even without the intervention of a cooling medium; therefore, when a cooling medium is employed, the degree of hardness is intensified. It has been stated—the writer would not like to confirm this view positively—that a piece of chromium steel of a given diameter, when quenched, would become hardened more deeply than a similar piece of carbon steel. Probably, if the right hardening temperature were obtained for each class of steel, it would be found that the chromium steel was, after hardening, tougher than the carbon steel, and it is also probable that it would harden at a somewhat lower heat, but that the effects of hardening would penetrate further is not yet proved.

Theories have been put forward that chromium holds carbon in the "combined" state, and that, therefore, chromium steel hardens more readily. Seeing that the carbon present in all steel is in the combined state, whether chromium is present or not, this explanation does not offer much satisfaction.

From the results of the labours of our President, Sir Frederick Abel, Dr. Sorby, Profs. Osmond and Ledebur, Mr. J. W. Spencer, and others, it has now been clearly proved that, as the carbon in pig iron has several forms, so in steel there is more than the one usually termed "combined." Professor Ledebur's exhaustive papers on "The Nomenclature of the Various Forms of Carbon Occurring in Iron" (*Stahl und Eisen*, November 1888), and "Recent Experiments on Carbon and Iron" (*Ibid.*, April 1891), seem to have escaped notice on this side. It would be of considerable benefit if this worker could be induced to give the Iron and Steel Institute a paper on his latest researches. He has clearly proved the existence of four distinct forms of carbon—

hardening carbon, carbide carbon, temper carbon or graphitic temper carbon, and graphite. The exact rôle played by each is further complicated by their being again split up into different forms or combinations as carbides of iron.

There is no doubt that elements such as chromium, tungsten, and silicon, alloyed with carbonaceous iron, including steel, have considerable influence upon the carbon or carbide of iron present, probably more so than upon the iron itself. A substance of very complex nature is thus obtained, and it is not to be wondered that its study is no easy task. Thanks especially to the labours of Professor Roberts-Austen and M. Osmond, by the accurate study of thermal treatment, we are gradually approaching a more satisfactory state of knowledge on these particular points.

Chromium has, without doubt, a marked action upon the different states of carbon or carbides of iron into which they are further divided, according to the thermal treatment to which the alloy has been subjected.

Very high tensility has been got with hard chromium steels, the writer having obtained specimens with 104 tons per square inch, and about 3 per cent. ductility. M. Brustlein showed an excellent series of samples at the 1889 Paris Exhibition, one of the test-bars having a tensile strength of 100 tons per square inch. No analysis accompanied the specimens, so that the results did not enable a comparison to be made. The tests are given in Table XIV.

Whilst the softer chromium steels do not require special care, harder varieties are as liable as carbon steel—if not more so—to become burnt and spoilt by overheating, and to give material with coarse and weak crystallisation. Chromium steel in the harder grades, and when properly manufactured, gives an exceedingly fine-grained product. M. Boussingault mentions that cemented cast steel of ordinary description acquired large crystals, whilst cemented chromium steel (chromium-carbon) had only small ones, showing the power of chromium in the chromium-carbon combinations to reduce the size of the crystals.

That chromium has a strong action on the crystalline formation is shown by the acicular structure of most of the ferro-chromium produced.

The Terre-Noire Co. exhibited at Paris in 1878 a chromium

steel (75 per cent. Cr.), and pointed out its high resistance in compression. No doubt, in this respect, in harder qualities it is well suited to resist compression stress, owing to its closeness and density. Here, again, the proviso must be made, "so long as there is sufficient carbon present;" for from Table IV. (Diagrams III. and IV.), it will be seen that, in the absence or lowness of carbon, chromium steel gives no special resistance to compression—in fact, it is but slightly superior to steel containing like percentages of aluminium or silicon.

It appears that some of the Tasmanian chromium pig brought during 1876 into this country by Mr. Riley was sent to Sweden. Tests were there made of it by the open-hearth process. It is stated that the steel was of good quality, though sufficient details are not given to show that it possessed any marked advantage over ordinary carbon steel.

Mr. Riley in 1890, during the course of a discussion before the Society of Chemical Industry on Feodosieff's new method of tempering and hardening steel, stated that several hundreds of tons of chromium iron had been used in Sheffield for tyres and axles owing to the superiority obtained in the products, and the severe test they would stand under a falling-weight test. The writer tested the same pig iron, but its lowness in chromium made it unsuitable for most alloy purposes.

The only recent paper on the subject of chromium steel has been that read by Professor Arnold before the Institution of Civil Engineers, 1888, on "The Influence of Chemical Composition on the Strength of Bessemer Steel Tyres" (*Minutes of Proceedings*, vol. xcv.). This paper had for its object to describe a special quality of steel, and much interesting information was given respecting the employment of chromium steel for tyres. The tensile tests obtained by him, in addition to a large number of drop-tests on axles and tyres, were as follows:—

	Analysis per Cent.						Tensile Strength in tons per square inch.	Elongation per cent. on 2 inches by $\frac{1}{4}$ inch area.	Reduction of Area.
	C.	Si.	S.	P.	Mn.	Cr.			
No. 1.	·28	·08	·10	·09	1·54	·42	50	15	26
No. 2.	·32	·11	·05	·07	1·46	·30	50	16	29
No. 3.	·28	·11	·07	·07	1·41	·64	50	10	14

The test-pieces were prepared by hammering a 14-inch square ingot into $1\frac{1}{4}$ -inch square bars.

The material described being somewhat high in manganese (about $1\frac{1}{2}$ per cent.), it is difficult to determine the precise action of the chromium in the samples. Professor Arnold considers that chromium in small quantities raises the tensile strength of steel without seriously diminishing the ductility. No doubt the ductility obtained along with high tensility was owing to the chromium present, but it must also be borne in mind that the carbon in the steel described by Professor Arnold was not more than ·32 per cent.

Special attention is drawn to this point, as high carbon chromium steel may be incautiously manufactured. Bad results are sure to be obtained for structural purposes unless the carbon is kept comparatively low.

In Mr. Howe's work on "The Metallurgy of Steel," he mentions cases at the Pennsylvania Steelworks where Bessemer rails, with from ·12 to ·54 per cent. of chromium, successfully passed the drop-test, provided the carbon did not exceed ·30 per cent., but broke if this limit was exceeded. Thus chromium, when in presence of even a medium percentage of carbon, appeared to injure the shock-resisting power of the steel. It is to some extent difficult to reconcile the behaviour of this material with the chromium steel employed for armour-piercing projectiles. Such steel contains three or four times as much carbon and chromium as that named, yet with points suitably hardened they successfully withstand—without cracking or altering their form—being hurled, at a speed of nearly 2000 feet per second, against hard compound armour thickness nearly double the calibre of the projectile.

This difference, as compared with the behaviour of the steel referred to by Mr. H. M. Howe, is no doubt partly owing to the different character of the article, and to the fact that the points of the shells are of sufficient hardness to successfully penetrate the plates without deformation. The same projectiles with unhardened points would merely splash up against the plate.

Mr. Howe's excellent *résumé* of the principal facts connected with chromium steel are worthy of perusal by those interested in this subject. The metallurgical world is considerably indebted to him for his admirable treatise on the metallurgy of steel.

During the discussion which followed Professor Arnold's paper, it was stated by some of the leading metallurgists and locomotive engineers, that carbon steel of a temper (as regards the carbon percentage) higher than the chromium steel samples quoted by him gave as good, if not superior, results. In the writer's opinion, however, the chromium steel under discussion appeared at a disadvantage, being really a manganese-chromium steel, the percentage of the former metal being as high as 1.50. It is difficult to know why such a comparatively large quantity of manganese was present. It would have been fairer to compare a chromium steel of the same percentage of manganese as is ordinarily employed, say .75 per cent. to 1 per cent. From the Terre-Noire experiments in 1878 we know that manganese alone, without chromium, would confer high tensility.

At the top of the following table will be found the results of the Terre-Noire carbon-manganese steel tests.

It would seem, therefore, that chromium steel, in the instances quoted by Professor Arnold, was not in its best form to make a direct comparison with carbon steel.

The following table of tests with carbon and chromium steel may be of interest. The details given by some of the experimentalists are not sufficient to make them as complete as they should be, but they will enable a rough comparison to be drawn. As they represent practical tests, they may be useful for reference:—

Tests of Tyre Steel.

No.	Nature of Steel.	Analysis per Cent.					Elastic Limit.	Tensile, Tons per sq. in.	Elongation per Cent on 2 in.	Reduction in Area per Cent.	Remarks.
		C.	Si.	S.	P.	Mn.					
o.	Carbon-manganese { 33 30 21 56	46 51 56	...	...	...	1.06 1.30 2.00	Nil Nil Nil	41 52 57	21 15 9	...	Tensile of No. 33 when oil-tempered 82 tons. These samples were made in 1878 by the Terre-Noire Company, and were not for tyres. Average result of four tests. Annealed forty-eight hours in ashes. Described as "too hard." Do. Analysis of the steel received by Mr. Vickers. Believes even 70 per cent. C. would stand test. From G. W. H. engine tyre, which ran 41,000 miles in 18 years. Good tyre steel (6 ft. 6 in.—15 tons per pair of wheels) Mr. A. estimated should run 40,000 miles for each ½ in. worn. Do. Average of several hundreds of tests. A one-ton tup was allowed to fall seven times from a height of 13 ft. until tyre deflected ¼th of its diameter (5 ft. 6 in. exterior), but no sign of fracture. On 5-inch test-pieces. In some 16 tests of steel for tyres quoted by Kirkaldy, the tensile ranged from 22 to 51 tons per square inch, and elongated from 2 to 26 per cent.
	Carbon-manganese { 25 28 32 28	25 28 32 28	03 08 11 11	12 10 05 07	11 09 07 07	1.75 1.54 1.46 1.41	Nil 42 30 64	42 49 50 51	18 15 20 10	26 26 27 13	
	Chromium-manganese { " " " " " " " " Steel made from Tasmanian chrome pig-iron by Siemens' process.	...	...	...	...	...	...	...	...	...
	Carbon	60	19	...	...	46	53	57	18	...	
	"	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated	
Vickers	Carbon	60	...	05	03	50-70	Nil	...	...	...	...
Reynolds	"	...	...	...	...	...	Nil	36	...	...	...
Aspinall	"	65	28	09	06	86	Nil	46	...	...	...
Berkley	"	60	23	07	02	111	Nil	...	...	...	...
Rendel	"	...	...	...	...	...	...	47	20	21	...
Kirkaldy	Probably carbon steel	52	14	10	05	49	Nil	43	15	21	...
"	"	...	...	...	...	...	27	51	22	40	...
"	"	...	...	...	...	...	27	60	22	41	...
"	"	...	...	...	...	...	22	43	26	42	...
"	"	...	...	...	...	...	30	38	25	24	...

Although chromium steel, judging from this table, does not show any superiority to carbon steel, as before mentioned, it must be borne in mind that the samples quoted are really manganese-chromium steel. Besides, too, chromium steel for tyres and axles is being made in considerable quantities, and the writer understands that with it are obtained results not readily given by carbon steel. Judging from the tests of the writer, quoted in this paper—that is, of the carbonless chromium steel in which the manganese is very low—by judicious mixtures and treatment chromium steel of a good quality is to be obtained without such special attention to the low limits of sulphur and phosphorus as in carbon steel. Whilst further inquiry on this point does not come within the scope of the present paper, it seems to be of importance.

As pointed out during the discussion on Professor Arnold's paper—by Mr. G. Berkley, now President of the Institution of Civil Engineers—before users can express any leaning towards the adoption of chromium in place of carbon steel, it must be shown what are its special advantages. Mr. Berkley also pointed out that the spring steel tests (carbon steel) quoted by Professor Arnold, and noted in the following table, gave as high results as those of the chromium-manganese steel:—

Comparison of Carbon Spring Steel and Chromium Steel.

Source.	Nature of Steel.	Analysis per Cent.						Elastic Limit.	Tensility, Tons per sq. inch.	Elongation, per Cent. on 2 inches.	Reduction in Area per Cent.	Remarks.
		C.	Si.	S.	P.	Mn.	Cr.					
Arnold	Carbon	50	07	09	0.8	1.10	Nil	...	51	15	31	Spring steel.
"	Chromium-manganese	32	11	05	07	1.46	30	...	50	16	29	{ Chromium-manganese steel.

Whilst Mr. Berkley was justified in making this comparison on the samples in question, the writer would point out that in the chromium steel, had the manganese been within ordinary limits, it would probably have given as high tensility, but superior ductility.

Professor Arnold states that he considers 40 per cent. each of chromium and manganese produce the same hardening effect as 20 per cent. carbon. With the results of the writer's samples it is possible to see the exact effects of chromium upon iron, *e.g.*, samples "A" to "E," or perhaps to "G," in which the carbon, whilst not a negligible quantity, does not, at any rate, materially affect the product.

Whilst the statements in the paper quoted are in the main correct—first, that chromium added in small quantities raises the tensility of steel without seriously diminishing ductility; second, that when added in too high percentages it induces brittleness—both of these should be qualified by a third, *viz.*, that they are principally dependent upon, and qualified by, the percentage of carbon present. Chromium in itself, as clearly shown by the different diagrams accompanying this paper, does not, up to, at any rate, a certain percentage—say 75 or even 1 per cent.—materially affect the product, whether as regards yield-point, tensility, hardness test (Turner's), or hardness by water-quenching. Take, for example, specimen "D" in its annealed state (14 per cent. C., 5 per cent. Cr.); its yield-point is as low as 16 tons; its tensility 25.50 tons per square inch; its hardness in Turner's scale is but little higher than wrought iron, nor does it become hard when water-quenched from a welding heat.

Although our English engineers, probably owing to the high-class road-beds in this country, do not seem to be much troubled with broken tyres, those in Germany appear to be less fortunate, either owing to a lower quality of product, or to other causes. According to the *Sekundarbahn Zeitung* (p. 257) forty-two German railway companies, with 33,718 kilometres of line, have stated that 4123 breakages of tyres took place from 1st October 1880 to 1st April 1881. In 1887 there were 3552 broken tyres, 33 per cent. of which failed through causes unassignable.

Therefore, if an "alloy steel" can be produced with superior tensility, ensuring as high or higher durability than now, as well as superior ductility, there is, without doubt, room for its employment. One valuable property possessed by chromium steel, when properly manufactured, seems to be that of giving greater contraction of area in the testing-machine. No doubt this is partly

owing to its elastic limit being high, which, combined with high tenacity, causes striction to be more localised. As Mr. D. Kirkaldy points out—and his unique experience in testing material entitles his opinion to very careful consideration—high contraction of area at fracture is a proof of good quality, or body, in the steel. Those who favour chromium steel of the requisite quality will not overlook this point.

Unfortunately, at present there is so much lack of uniformity of tests, that it is often difficult to draw comparisons. Continental engineers are now seeing the importance of this point, and a very competent commission in France ("Commission des Méthodes d'Essai des Matériaux de Construction") is now endeavouring to bring into harmony the present discordant elements. It is to be hoped something may be done here in the same direction. If, too, we could sum up courage to decimalise our weights and measures, enormous convenience would result, as then the whole of this continent, and America* would probably soon follow suit, could compare notes by means of a universal metric system. This, combined with some uniformity of tests, both as to their nature and as to the manner in which they should be conducted, would prove invaluable, and help on the progress of metallurgy. Whilst it is quite possible to bring objections against the metric system, its advantages so enormously outweigh its disadvantages, that the matter is well worth some consideration. The Decimal Association is working hard in this direction, and it is to be hoped members of this Institute will give it every support. As to a uniform system of tests, this question also commends itself to most careful consideration.

Sir Philip Magnus, at the recent London Congress of the Chambers of Commerce of the Empire, made the following important statement: "In this country we were placed at a very great disadvantage through the retention of our present system. We were severely handicapping the education of our boys by compelling them to learn both the system of weights and measures which prevailed elsewhere, and the system which prevailed in this country."

* The U.S.A. have already proved the immense convenience of a decimal monetary system, and to some extent have introduced it into their weights by the 100 lbs. hundredweight and the 2000 lbs. ton.

The writer would point out that a convenient system of weights and measures, such as the metric system offers, and such as ours can never possess, must give those nations accepting it great advantages, and prove to be one of not the least important factors in determining the future of a country's industrial progress.

The foregoing is aside from the object of this paper, but the writer, having had the privilege of seeing the advance copies of the French Commission's valuable reports, has been greatly struck with the importance of English engineers also following up the subject of uniformity in tests.

If we do not follow suit in progressive advances in both the directions referred to, can we wonder that our trade rivals gain considerable advantages over us? By studying the convenience of a large portion of our customers, to say nothing of the advantages resulting to ourselves, we should certainly derive considerable benefit.

CHROMIUM STEEL WIRE.

By the kind assistance of Messrs. J. Shipman & Co., steel and wire manufacturers, Sheffield, the writer is able to give an interesting set of tests on samples of chromium steel wire. These are fully detailed in Table XV.

As will be seen from this table (specimen "B," .16 per cent. C., .29 per cent. Cr.), even thin wire (No. 20 B.W.G.), which would very rapidly part with its heat, could not be hardened, either with oil or water quenching.

The tensility of this sample in the annealed forged bar, 1½ inches in diameter, was 25 tons.

When drawn down to No. 20 B.W.G., annealed and re-drawn one hole, this is raised to 45 tons.

When again annealed it is practically the same, 44 tons.

Oil-quenched, it rises to 49 tons.

Water-quenched, it rises to 59 tons.

This differs but little from similar tests on mild steel wire treated in a similar manner.

Specimen "F" (.27 per cent. C., 1.18 per cent. Cr.), though

containing more than one quarter per cent. of chromium, would not harden either in water or oil. Therefore chromium, whilst stiffening the steel, cannot be termed a true hardener in the absence of sufficient carbon.

Sample "J" (.77 per cent. C., 5.19 per cent. Cr.) gives a good product, but does not show, except as regards better bending tests, any marked superiority over ordinary carbon steel. The carbon being .77 per cent. explains the reason why the report states "hardens nicely in water and oil."

That hardness by water-quenching does not necessarily mean increased tenacity is proved by the results obtained from "J" and "L," in which both the oil and water quenched specimens possess less tenacity than the original wire which had been drawn one hole after annealing. In fact, the figures are even less ("J"), and the same ("L") both for the oil and water quenched as compared with the annealed specimens. Except in semi-hard steels, such, for example, as "B" and "F," tensility is not apparently increased by water-quenching. Probably this partly explains the reason why hardened (that is, "dead hard") steel is more liable to spontaneous cracks; the steel has really *not* a high tensility, as is often imagined, and it is therefore not in the condition to resist high stress.

"L" specimen, containing .70 per cent. C., and as high as 9.18 per cent. Cr., possesses no special features. It is somewhat higher in breaking strength and ductility than ordinary steel of 1.30 per cent. carbon—that is, comparing the samples in their annealed and one-hole drawn state.

Probably the wire-drawer had not exactly hit the right tempering heat, but it is curious to note that "L" does not harden so readily as specimen "J." This is singular, because the chromium is nearly 50 per cent. higher, and the material should therefore be much harder. M. Osmond also found that "L," when subject to certain thermal treatment (detailed in his report accompanying this paper), does not become hard so readily as "J."

Messrs. Shipman kindly made some comparative tests on carbon steel wire of different qualities; these will also be found in Table XV. Unfortunately, a complete comparison cannot readily be

made, owing to the tests of the carbon steel having been made with wire of No. 12½ B.W.G., whilst those of the chromium steel were No. 20 B.W.G.

ELECTRICAL PROPERTIES.

Dr. Hopkinson has kindly made a number of experiments with chromium steel, and reports the following results:—

Table VI., and the curves shown in figs. 14 and 15, give the magnetic properties of the chromium steel marked "L." Table VII. shows the resistance of the four samples "B" (16 per cent. C., 29 per cent. Cr.), "F" (27 per cent. C., 18 per cent. Cr.), "J" (77 per cent. C., 519 per cent. Cr.), and "L" (71 per cent. C., 918 per cent. Cr.). Dr. Hopkinson says these resistances may not be so minutely accurate as they might be, owing to the wire having in places become oxidised in the heating. He also states that, as regards the sample marked "L," while it might have been expected to have an abnormally low critical temperature, as it is an alloy similar to nickel and manganese steel, both of which have low critical temperatures, that is not the case, the critical temperature differing but little from that of wrought iron.

The writer considers that, although chromium steel is an alloy, yet its properties in mechanical and other tests would lead one to expect it to behave very differently, as compared with either manganese or nickel steel.

The coercive force, especially when the material is hard, is great. In this state, Dr. Hopkinson considers that it should make good permanent magnets—a fact confirmed by Dr. Bottomley's tests, mentioned later.

It will be noticed that annealing has a marked effect on the curve of magnetisation, diminishing, as is usual with steel, the coercive force.

The electrical resistance of all four samples is high, but with the two samples of intermediate composition, which harden best when quenched, not so high as manganese steel; the resistance is materially increased by quenching.

MAGNETISATION OF CHROMIUM STEEL.

Dr. Bottomley of Glasgow has kindly made a series of tests with the following results respecting the magnetisation of chromium steel:—

				C.	Cr.
1 Bar	§ in. sq.	27 in. long,	1176 A, <i>unannealed</i> ,	·07	·22 per cent.
1 „	§ „	27 „	1176 E, „	·12	·84 „
1 „	§ „	27 „	1176 H, „	·39	2·54 „
1 „	§ „	27 „	1176 K, „	·86	6·89 „

Also one of each of the above in the *annealed* state.

The four unannealed bars (marked “A,” “E,” “H,” and “K”) were magnetised to saturation in a field of approximately 400 C. G. S. (absolute magnetic measure), and their magnetic moments were determined immediately thereafter. They were found to be

A.	E.	H.	K.
34·86	40·69	62·82	84·07

Observations of the magnetic moments of these bars were made daily for nineteen days, the magnets remaining undisturbed mechanically and magnetically, except as to the carrying of them to and from the testing-place. The percentage loss in the nineteen days was found to be—

A.	E.	H.	K.
Per Cent.	Per Cent.	Per Cent.	Per Cent.
8	6·77	5·84	4

Most of this loss, as is always the case, took place during the first day or two.

Dr. Bottomley, for the sake of comparison, adds that two bars of excellent steel, with which he had been well acquainted for a number of years, were magnetised and tested in a precisely similar way to the unannealed bars above referred to. These were marked “M” and “M’.” Their magnetic moments per gramme immediately after magnetisation were—

M.	M’.
80·4	79·12

and their loss during nineteen days—

M.	M’.
Per Cent.	Per Cent.
5	3·4

It appears, therefore, that the bar marked “K” is of an

exceptionally high magnetic quality. Experiments are now in progress for the purpose of finding the loss by mechanical jarring, tapping, slight falls, and afterwards heavy falls on a wooden block, and so forth. This is of great importance for practical purposes.

The four unannealed bars have also been partially tested for susceptibility and retentiveness, great susceptibility and small retentiveness being the qualities desirable in *soft iron*. Broadly speaking, bars "A" and "E" are much more susceptible to small magnetising forces than "H" and "K," and retain much less than "H" and "K" when the magnetising force is annulled. These experiments are not yet concluded.

CONCLUSION.

In conclusion, the writer would specially thank the different friends named in the paper, who have so willingly furnished that correlation of evidence which it is now so important to have when studying the properties of a complex body like steel, and such as the chromium steel under consideration. It is hoped, by means of this correlation—including chemical composition, mechanical, physical, and electrical properties, microscopic character, and, finally, by the admirable and systematic research work of M. Osmond on behaviour under thermal treatment—that a knowledge of the properties of the special alloy under consideration has been made as complete as is at present obtainable.

APPENDIX.

A.

DEPOSITION OF CHROMIUM.

In Watt's "Electro-Deposition" the following particulars are given respecting the deposition of chromium:—

"In his investigation concerning the electrolysis of metallic salts, Bunsen determined the causes which most influence the separation of the metal; those causes are two in number, the principal of which is owing to the *density* of the current, and the other to the greater or less concentration of the electrolyte. By density he means the concentration to a single point of 'the electrical undulations, in a manner analogous to the concentration of luminous or calorific rays in the focus of a concave mirror. Let us take, for example, a charcoal crucible in communication with the positive pole of the battery, and place it in a small capsule of glazed porcelain containing the liquid to be decomposed. The space between the crucible and the capsule is filled with hydrochloric acid, and the liquid of the small capsule is put in communication with the battery by means of a thin sheet or wire of platinum. (For this purpose the platinum wire must be exactly in the centre of the crucible; if not, by virtue of its tendency to take the shortest road, the current is established in preference between the nearest points.) The current is then established between a large surface, the charcoal crucible, and a fine platinum wire, in which it is concentrated; the effects are added in this direction, and the fluid becomes capable of overcoming affinities which have hitherto resisted powerful batteries.' The apparatus just described is placed in a porcelain crucible, which is kept warm in a sand-bath.

"By the above arrangement Bunsen succeeded in separating chromium with perfect facility from a concentrated solution of its chloride. The deposited metal, which was chemically pure,

presented the appearance of iron, but was less alterable in moist air. It resisted the action of even boiling nitric acid, but was acted upon by hydrochloric acid and dilute sulphuric acid. Bunsen found that when the current was diminished the metal ceased to be deposited in the metallic state, but appeared as a black powder consisting of protoxide and sesquioxide of chromium."

In the *Engineering and Mining Journal* of 16th July 1892, there is also given the following information respecting the electrolytic deposition of chromium:—

"The following solutions for chromium plating are given by Messrs. Placet & Bonnet in the *Moniteur Industriel*, No. 25:—

"1. Chrome alum, 10 to 15 parts; alkaline sulphate, 10 to 15 parts; oxalic acid, 5 parts; and water, 100 parts. This solution is heated until it turns violet. Any organic acid may be used.

"2. Chromium sulphate, 15 to 20 parts; water, 100 parts. Sulphuric acid to acidulation.

"3. Alkaline chromate or bichromate, 10 to 15 parts; chrome alum, 15 to 20 parts; and water, 100 parts. Many other salts can be used instead of the chrome alum in the solution. The chromium is deposited at the negative pole. While the deposition takes place at ordinary temperatures, it is more rapid when the solution is warm. It is also assisted by the addition of sugar, alcohol, or glycerine."

B.

The patent of Mr. James Park, of Millburn Chemical Works, Glasgow, is described in Specification No. 377, 1888. The following are the claims:—

1. Obtaining chromium by first heating bichromate or other chromate of ammonium and sugar, or other suitable carbonaceous matter, to obtain a mixture of oxide of chromium and carbon; secondly, heating the oxide of chromium and carbon to form spongy chromium; and thirdly, heating the spongy chromium to form compact or solid chromium substantially as hereinbefore described.

2. Obtaining chromium by mixing oxide of chromium obtained
bichromate or other chromate of ammonium with carbon;

and heating the mixture to form spongy chromium, and by subsequently heating the spongy chromium to form compact or solid chromium substantially as hereinbefore described.

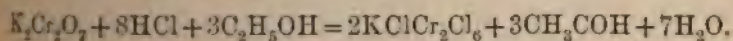
3. Obtaining oxide of chromium by heating bichromate or other chromate of ammonium substantially as and for the purposes hereinbefore described.

C.

"PREPARATION OF CHROMIUM," by Dr. Em. Glatzel, Lehmdamm, 6-2, Breslau.

(From the *Journal of the Society of Chemical Industry*, February 28, 1891.)

Potassium chromic chloride is reduced by magnesium in the presence of potassium chloride. 100 grms. of potassium bichromate are dissolved in as little water as possible, and to the solution are added 400 c.c. of hydrochloric acid (sp. gr. 1.124), and then 100 c.c. of 80 per cent. alcohol potassium chromic chloride is obtained according to the equation—



To the solution so obtained, 160 grms. of potassium chloride are added, and after filtration the whole is evaporated to dryness, and further heated. Green particles are removed, and the mass is then powdered and mixed with 50 grms. of magnesium cuttings; that is, about double the quantity theoretically necessary. The mixture is raised to a red heat for half an hour in a covered Hessian crucible. On cooling, the crucible is broken, the dark grey mass is freed from particles of chromic oxide, and is then thrown into water. By decantation the potassium chloride and magnesium chloride are got rid of, and then the excess of magnesium and the magnesia are removed by the aid of dilute nitric acid. The chromium is finally dried on the water-bath. It is obtained in such a finely divided state that filtration cannot be used in the foregoing purification processes.

As obtained, the chromium consists of microscopic crystals almost white. Rubbed in an agate mortar, it shows metallic

lustre. Its specific gravity at 16° C. is 6.7284 (Wohler found 6.81 at 25°; Bunsen 6.7). A magnet has no effect on the metal. —T. L. B.

In "Clarke's Constants" Bunsen is stated to give it at 7.3, and the metal, according to Loughlin, reduced from KCy. 6.2.

D.

NEW METHOD OF MAKING CHROME-MANGANESE IRON.

(Extracted from "New York Mining and Engineering Journal.")

A proposition has been made to utilise Bessemer slag, which consists in grinding it fine, adding chrome ore, and mixing these with tar, so as to form the mass into blocks, and then smelting them down in the blast furnace. The product is chrome-manganese iron, the manganese emanating from the acid cinder. For instance, if Bessemer slag containing $\text{SiO}_2=45$ per cent., $\text{FeO}=10$ per cent., MnO 45 per cent. is intimately incorporated with chrome ore of the following contents— $\text{Cr}_2\text{O}_3=50$ per cent., $\text{Fe}_2\text{O}_3=12$ per cent., $\text{Al}_2\text{O}_3=11$ per cent., $\text{MgO}=18$ per cent., $\text{SiO}_2=9$ per cent. and the necessary carbon, and the mixture be reduced by melting, the following alloy will approximately be obtained—20 per cent. Mn., 50 per cent. Cr., 26 per cent. Fe., together with a slag which contains, say, up to 50 per cent. SiO_2 , 1 to 2 per cent. FeO , 14 per cent. Al_2O_3 , 18 per cent. MnO , 16 per cent. MgO , and only traces of Cr_2O_3 . The separation of the metal from the slag is perfect because the Bessemer cinder forms an excellent solvent for the otherwise almost infusible earths accompanying the chrome ores; and again, because the manganese in the chrome alloy, which of course will depend on the quality of the Bessemer slag employed, makes this metal quite fluid. The exact quantity of manganese in the alloy can, of course, be obtained by adding manganese ores as required.

REPORT ON THE CHROMIUM STEELS OF MR. R. A. HADFIELD.

(The photographs of the micro-structure of these steels will be found in Fig. 19.)

By F. OSMOND, PARIS.

STRUCTURE.

1176 B.

Forged into bars of $\frac{1}{4}'' \times \frac{1}{4}''$.—Etched by dilute nitric acid (1 vol. acid at 36 Beaumé, and 4 vols. of water) for thirty seconds, or by Sir Fredk. Abel's reagent for one minute.

The structure is only visible under high powers.

An ordinary steel with 0.16 per cent. of carbon is composed of polyhedric grains or crystals of lamellar structure, between which the carbide of iron Fe^3C is irregularly disposed.* The surfaces of contact between the grains themselves form the surfaces of least resistance along which disruption takes place, so that the resistance to breaking of a mild steel represents the cohesion of the grains, and not the resistance of the grains themselves.

The structure of B. is quite different to this. In it may be distinguished small spots of greater and small spots of lesser brightness; but when a sufficiently high magnifying power is employed, it may be seen that the whole mass is formed of what Mr. Werth and I have called "simple cells," that is to say, of small granulations of iron agglomerated without any geometrical order, with or without the interposition of carbide of iron. The most brilliant points or spots are those in which the iron is purest and most compact; the dark spots are more carburised or more porous, or both. There is, however, no very distinctly marked line of division between the regions of unequal brightness, as in ordinary steels; the passage from one to the other is gradual and undefined.

This structure appears to be excellent, and is characterised by strong fracture. A somewhat similar structure might be obtained

* *Journal of Iron and Steel Institute*, 1891, vol. I., pl. i. and ii.

in the case of ordinary steels of the proper degree of hardness by water hardening and later tempering or by lead quenching.

Photograph was taken for purposes of comparison with an enlargement of 80 diam. But in reality this only showed the relative absence of structure, the details being too delicate for my apparatus to be capable of reproducing them.

There still remains the question how far the observed structure is due to chromium or to forging at a low temperature. This we may ascertain by examination after annealing.

Annealed at 1030° C. (see photograph).—The light and dark portions are a little better individualised than before the annealing, and the structure approaches more closely to that of a steel without chromium of the same degree of hardness. With this reservation, the description of the forged metal might be applied to the annealed metal. It might be said that the steel shows no traces of crystal-line structure. Thus chromium, when present even to the small amount of 0.29 per cent., interferes very considerably with the formation of crystals of iron and their separation from the cement.

1176 C.

Forged into bars of $\frac{1}{4}$ " \times $\frac{1}{4}$ ".—Etched by nitric acid 20 per cent. vol. for twenty to twenty-five seconds. High power required.

The grains are a little better individualised than in B., even when annealed. However, they are not distinctly detached from the darker matrix, and the structure is still that of simple cells.

In this instance photography was not employed. It would have shown an appearance intermediate between that of B and F.

The appearance of the sample indicates an amount of carbon at least equal to that of B, say about 0.20 per cent., instead of 0.05, as shown by analysis. The cooling curves, as will be seen later, confirm this indication.

Annealed at 1030° C.—Has not been examined.

Annealed at 1250° C.—The crystallisation of the iron in "dendrites" took place pretty much as in the case of ordinary steels (see the photograph).

1176 E.

Forged into bars of $\frac{1}{4}'' \times \frac{1}{4}''$.—Etched by nitric acid at 20 per cent. vol. for twenty seconds.

The grains were more distinct than in C., display a tendency to subdivide into laminae, and are easily distinguishable from the darker matrix—the latter being apparently formed of granules of iron surrounded by carbide. The structure is therefore composite, consisting of a mass of "simple cells" enclosing embryonic "compound cells." However, the passage from one to the other is less sudden than in the case of ordinary steels of the same degree of hardness, and the average diameter of the cells is much smaller (0.005 mm. instead of about 0.03 mm.).

The result of forging is to cause the grains of iron to arrange themselves in parallel lines separated by dark bands, at least in those parts which have been subjected to the maximum pressure; and this is also the case with the other samples.

If a photograph had been made, it would have shown an appearance similar to that of F.

The amount of carbon present would be somewhere about 0.25 per cent. (instead of 0.12), according to the indications shown by the cooling curves.

Annealed at 1030° C.—The grains of iron are clear and distinct, and the structure does not differ much from that of an ordinary steel of the same degree of hardness, except by the small size of the grains, which are much smaller (about five times in diameter and 125 times in volume). The photograph shows the general appearance of F. when annealed, though the dark matrix is less extensive owing to the smaller content of carbon.

1176 F.

Forged into bars of $\frac{1}{4}'' \times \frac{1}{4}''$.—Etched by nitric acid 20 per cent. vol. for fifteen seconds. (See photograph magnified 80 and 300 Dias.)

The bright points, having a mean diameter of 0.015 mm., or thereabouts, are small composite cells of lamellar iron; the dark matrix appears to be formed of simple cells of iron cemented

together by carbide; but I have not been able to see any trace of the alternate layers of iron and carbide, first observed and described by Dr. Sorby in his admirable researches. The absence of the lamellar structure is general in all the chromium steels, whether forged or annealed.

The amount of carbon present may be estimated at 0.35 per cent.

Annealed at 1030° C.—The effect of the annealing is the same as in the case of E. The grains of iron are a little larger and reach a diameter of 0.01 mm. The passage of the granules into the matrix is less distinct than in the case of ordinary steels.

1176 J.

Forged into bars of $\frac{1}{4}$ " \times $\frac{1}{4}$ ".—Etched by nitric acid of 20 per cent. vol. for ten to fifteen seconds. The tint assumed was that of black hardening carbon. This steel is very hard (self-hardening).

This metal is characterised by the presence of a number of small white points of great hardness and brilliancy, which are scarcely at all attacked by the acid (see photograph). These white points, which we find to be much more numerous in sample L., appear to be compound of iron, chromium, and carbon.

The matrix has the structure of an hardened steel, and is entirely composed of simple cells of about 0.001 mm. in diameter. The photograph shows the white points well, and also the fact that composite structure is absent.

Annealed at 1030° C.—No notable change of structure; metal softer, but still hard.

Annealed at 1320° C.—Complete change of structure. Etching with acid, which must be continued thirty seconds, shows large brilliant grains of irregular shape and size, and sharply distinct from the dark matrix. These brilliant portions are very hard, although they do not show the reaction of hardening carbon when treated with nitric acid; they appear amorphous, and, in accordance with the result of my experiments, I am inclined to attribute them to solution of the hard compound which we found isolated in the metal when less heated. The dark matrix is of ordinary steel.

1176 L.

Forged into bars of $\frac{1}{4} \times \frac{1}{4}$ inch.—Etched with nitric acid of 20 per cent. vol. for ten to fifteen seconds. The etched surface is not so black as that of J.

The brilliant white points which we have discovered in J. are infinitely more numerous, although preserving the same specific characteristics; their form is spheroidal and more or less regular, and their diameter 0.001 mm. to 0.01 mm. The photograph with the enlargement of 300 D shows the general appearance in this sample, and reminds one to a great extent of a starry sky. The dark matrix, which the photograph does not resolve, is entirely composed of simple cells.

Annealed at 1320° C.—The effect of this high temperature is similar to that noticed in J.; but, as the amount of chromium which it contains is very much greater, the transformation of the matrix into hard metal, little capable of being reacted upon by acids, and no longer showing the reaction of hardening carbon, is almost complete. The steel is composed of comparatively large polyhedrons (0.08 mm. to 0.2 mm), but they are much smaller than they would be in the case of ordinary steel heated to the same temperature. The etching with nitric acid may be continued as long as two minutes without sensibly altering the appearance of the sample. The polyhedrons continue brilliant and highly polished. The photograph shows the polyhedrons separated by black joints presenting a bright middle line; these joints are possibly simple fissures, or perhaps a residue of unconverted steel. The few traces of polish which the great hardness of the metal prevented from disappearing are easily discernible.

Annealed at 1320° C., quenched from 1320° C. to cherry-red, and then cooled in the air.—Etched by nitric acid 20 per cent. vol. for two minutes.

The state of the metal is the same as above, but, as might be foreseen, when the cooling is more rapid the size of the polyhedral grains diminish. These latter are not more than 0.05 mm. average diameter, and are more coherent. The joints are extremely

fine, and can be well seen by a microscope, but not easily in the photograph.

Annealed at 1320° C., again heated to a cherry-red and cooled in the air.—The structure is not altered.

Annealed at 1320° C., then reheated and forged into cherry-red and cooled in the air.—The forging causes the special structure due to the annealing at 1300° to disappear, and it reverts to that of the original bar.

Conclusions.

In conclusion, it appears that the chromium interferes with and impedes the crystallisation of the iron to a considerable extent, in this way reacting upon the structure:—

1. By the absence of Sorby's alternating lamellæ.
2. By the absence or diminution of the granular structure, as shown by Mr. Brustlein in his publications on chromium steels.

This action of chromium persists at all temperatures, but it is, generally speaking, much more distinctly marked when the temperature of 1000° or thereabouts is not exceeded, than in the case when we reach 1200° or 1300° C.

The effect produced by the chromium is not proportional to the amount of chromium which the metal contains. The small amounts (B. and C.) are relatively more active than the medium amounts (E. and F.). In the first case the chromium appears to be dissolved; and acid dissolves the steel without leaving any residue. As the amount of chromium increases, the compound of iron, chromium, and carbon appears to be formed, which is only partially attacked by acid, and possesses great hardness. (This is what takes place in silicon iron.) This hard compound may even be isolated in the form of globules, as shown in the case of the forged samples J. and L.; or it may be dissolved at high temperatures (1200° C. and higher) in the metallic matrix, bestowing upon it a high degree of hardness (J. and L. annealed at 1300°).

The absence or diminution of the size of the grain probably plays an important rôle in the modifications which the chromium effect⁺ mechanical properties of steels.

LAWS OF COOLING.

Experiments were conducted under exactly the same conditions as my former experiments with other steels.*

The results are shown graphically in two different ways. With the samples 1176 B., C., E., F., which did not show any real recalescence, the temperatures were taken for abscissæ, and the intervals of time which elapse between the passages of the luminous index over the successive subdivisions of the pyrometer scale were taken as ordinates (fig. 18).

In the graphic representation (figs. 16 and 17) for the samples J. and L., in which real recalescence took place, that is to say, the rise of temperature during natural cooling, it is the temperatures which have been taken as ordinates; the abscissæ being the time which elapses from the commencement of the cooling.

For the critical points I employ the symbols a_{r1} , a_{r2} , a_{r3} , which I have explained in the paper alluded to above.

The curves show, in the first place, a certain divergence between the amounts of carbon found by analysis and the value of a_{r1} .

The point a_{r1} , which represents the transformation of hardening carbon into combined carbon, lasts about in the case of—

1176 B.	20 seconds.
1176 C.	22 "
1176 E.	29 "
1176 F.	38 "

This leads to the conclusion—assuming that the content of B. is correct—that the other samples contain about—

1176 C.	0·18 instead of 0·05 per cent.
1176 E.	0·25 instead of 0·12 "
1176 F.	0·35 instead of 0·27 "

The difficulties presented by the estimation of carbon in the presence of chromium may explain these differences.

The position of the critical points for the different samples cooled from 1030° is given in the following table:—

* *Journal of the Iron and Steel Institute*, 1890, Part I., pp. 38-71.

	A_{r_1}			A_{r_2}			A_{r_3}		
	Begin- ning about	Maximum between	End about	Begin- ning about	Maximum between	End about	Begin- ning about	Maximum between	End about
1176 B	865	845-835	825	755	740-730	720	680	680-670	660
1176 C	835	810-800	785	740	720-710	700	690	680-670	660
1176 E	825	805-795	785	740	720-710	700	700	690-680	670
1176 F				780	760-750	725	700	700-690	680
1176 J				780	740 incomplete	720	Recalcescence at 682-692		
1176 L							Recalcescence at 684-704		

This table suggests the following reflections:—

a_{r_3} —the progressive decrease of a_{r_3} in samples B. to L. is easily explained by the progressive increase in the amount of carbon. This decrease would be even more rapid if the chromium were absent.

The chromium, as I have already shown in the Unieux steel, does not lower a_{r_3} in the conditions of cooling which have been considered, and which are the ordinary conditions under which my experiments were carried on. It does not, however, maintain the iron in the condition β , and consequently does not cause hardness in the absence of carbon.

We know, on the other hand, that bodies whose atomic volume is greater than that of iron (silicon, aluminium, phosphorus, arsenic), have a tendency to make a_{r_3} disappear. The curves of samples B., C., E., and F., do not show that chromium produces the same effect; but it should be remarked—

(1.) That the atomic volume of chromium (7.7) is only a very little greater than that of iron (7.2).

(2.) That the action of increasing amounts of chromium is struggling with that of increasing amounts of carbon.

a_{r_2} —The action of chromium is not noticeable.

a_{r_1} —The progressing elevation of a_{r_1} from B. to L. is explained by the increase in the amount of carbon.

In addition, the absolute position of a_{r_1} is in all cases somewhat higher than it would be if chromium were absent, as we have already shown in the case of the Unieux steels. The chromium,

therefore, hastens the transformation of "hardening-carbon" into "annealing-carbon" during the cooling of the steel, *at any rate in the conditions under consideration*; on this part it is not a cause of hardening.

The Rate of Cooling.—It is well known that, in the case of all steels, the critical points are lowered when the rate of cooling increases, and that when the limit is reached the chemical or molecular phenomena represented by these critical points partially or altogether disappear. It is on this fact that I have founded the theory of hardening; and it would be interesting to see whether the chromium does not produce an effect upon it.

With the Leclercq and Forquignon furnace, which I employed in my experiments, it is easy to cause the rate of cooling to vary. In general, when the temperature has arrived at the desired point, I shut off the gas and air jets, and remove the cover from the furnace, and in this way I obtain what I call *normal cooling*. It is under these conditions that the previous experiments have been made.

I obtain a *retarded cooling* by leaving the cover on.

I obtain a *hastened cooling* by removing the cover, and leaving the cold-air tap open.

Finally, withdrawing the bars from the tube and letting them cool in the air, *rapid cooling* is obtained (the most rapid which it is possible to follow with the chronograph).

I have examined from this point of view the samples C. and J. The results are given in the following table:—

1176 C. (Fig. 18).

Cooling from 1030° C.	Ar ₃			Ar ₂			Ar ₁		
	Begin- ning.	Maxi- mum.	End.	Begin- ning.	Maxi- mum.	End.	Begin- ning.	Maxi- mum.	End.
Normal	835	810-800	785	740	720-710	700	690	680-670	660
Hastened	830	810-800	780	730	710	695	680	670-660	650
Rapid in air	770	750-740	730	710	690	680	660	640-630	610

It will be seen that the lowering of the critical points is but slight in the case of the hastened cooling, and more noticeable in

the case of the rapid cooling; but, in the absence of chromium, the variations have been shown to be of the same magnitude; the chromium, up to an amount of 0.48 per cent., does not exercise any marked effect.

1176 J. (Fig. 16).

Cooling from 1030°.		Ar ₃₋₂₋₁
Retarded	recalcescence	691°-699°
Normal		682°-692°
Hastened		648°-665°
Rapid (in air)		no recalcescence.

The influence of chromium, or, more probably, of the chromium compound of iron and carbon, of which we have proved the existence in examining the structure, is in this case considerable. During the cooling in the air, the bars of $\frac{1}{4}$ " no longer show recalcescence—that is to say, the steel in question is as well hardened by simple cooling in air as any ordinary steel by quenching in water. Nevertheless, the steel L, which contains more chromium than J. (9.18 instead of 5.19), with a little less carbon (0.71 instead of 0.77), does not harden by cooling in air, the other conditions being the same. The amount of manganese (0.61 instead of 0.25) contained in J. must then be taken into account, as it causes lowering of the critical points; it is also probable that the amount of active compound of chromium, iron, and carbon in the *dissolved condition* is greater than in the case of L, where the compound takes more easily the form of isolated nucleus.

Influence of Initial Temperature in Cooling.

1176 C. (Fig. 18).

Cooling from	Ar ₃ .			Ar ₂ .			Ar ₁ .		
	Begin-ning.	Maxi-mum.	End.	Begin-ning.	Maxi-mum.	End.	Begin-ning.	Maxi-mum.	End
1030° C.	835	810-800	785	740	720-710	700	690	680-670	660
1250° C.	825	790-780	770	750	730-720	690	680	670-660	650

If the initial temperature rises from 1030° to 1250°, a_{r3} is lowered by about 20°, and a_{r1} by about 10°. The effect of 0.48 of chromium is thus doubtful in the case of a_{r1} , and marked in the case of a_{r3} to

such an extent that the latter point is not displaced under the same conditions in the absence of chromium.

1176 J. (Fig. 17).

Cooling begins at	835° C.	Recalescence Ar_{3-2}	713 to 716° C.
" "	1030° C.	" "	682 to 692° C.
" "	1220° C.	" "	635 to 643° C.
" "	1320° C.	Slackening	640 to 600° C.

In proportion to the increase in the initial temperature the recalescence is lowered rapidly; when the cooling begins at 1320°, there is no longer any real recalescence, and the heat disengaged is much less than the normal amount.

1176 L (Fig. 17).

Cooling begins at	750° C.	Maximum of Ar_{3-2}	
		Nothing	
" "	800° C.	Slackening from	753 to 744° C.
" "	920° C.	" "	714 to 704° C.
" "	1030° C.	Recalescence	684 to 704° C.
" "	1240° C.	Slackening (incomplete)	635 to 625° C.
" "	1320° C.	" (very incomplete)	615 to 600° C.

As in the case of J., the influence of the initial temperature is much more considerable than in the case of ordinary steels. All the coolings being conducted under the same conditions, the quantity of heat evolved during the cooling commencing at 1230° is incomplete, and that which is disengaged during the cooling commencing at 1320° is much less. Thus for J., as for L., if the initial temperature on commencing the cooling is sufficiently high, *the annealing produces the ordinary effects of hardening*. J. and L. when cooled from 1320° are very hard, and this fact would certainly be found to have important applications if the metal thus hardened should not become like a burnt steel, *i.e.*, very fragile.

This curious property of chromium appeared to be due, as has already been pointed out when considering the structure, to solution in the mass of metal of the hard compound of chromium, iron, and carbon. This compound would not have sufficient time to aggregate during the cooling which I employed, though it was rather slow; but it would probably happen during a still slower cooling, for Mr. Hadfield has not succeeded in hardening in

this process anything but bars of small dimensions. The forging would also appear to facilitate liquation.

However that may be, the hardness resulting from heating up to 1300° is very stable, and does not disappear on reheating to cherry-red, as in the case of ordinary tempered steel. Magnets manufactured from this metal would probably possess the qualities of great permanence.

Finally, I would draw attention to the great amount of space which exists between the critical points during the heating and cooling, respectively. The coolings of L., beginning at 750° and 800° C., show that $a_{\gamma\beta-1}$ is not commenced at 750° and not complete at 800° , since the recalescence is not normal during subsequent cooling. The transformations of iron and carbon are thus progressive during the heating, and consequently the mode of conducting the operation of hardening may be varied within wide limits.

POINTS OF FUSION.

After the last experiment with L. the shape of the bars was very much altered near the spot at which the couple was inserted. The maximum temperature shown by the latter had been 1325° to 1330° ; as two points of the same bar separated by less than half an inch could not possibly be of very different temperatures, it is plain that the melting-point of L. would not be very much higher than 1330° , unless this metal should pass through a prolonged pasty condition. But such a condition supposes the fusion of one of the constituents. Steel containing the same amount of carbon without chromium does not melt until the temperature is about 1420° .

In the case of J., the temperature rises regularly to 1380° . At 1380° , the luminous index begins to oscillate, showing that the point of fusion is nearly reached. The experiment was then stopped, and the bars were found to be slightly altered in shape. The metal consequently became very much pasty.

GENERAL CONCLUSIONS.

It appears to result from all these experiments that chromium may exist in steel in three states at least, either separately or simultaneously.

1. In the state of dissolved chromium.
2. In the state of a compound of chromium, iron, and carbon, in the form of isolated globules.
3. Also the same condition in the form of a solidified solution.

Pure chromium dissolved in pure iron does not appear to have any physico-chemical action, and would not have any other effect than that of interfering with the crystallisation of the iron; but this effect is none the less extremely interesting, from the point of view of the mechanical properties.

The triple compound, in the form of isolated globules, is very hard. When incorporated with a more malleable matrix, it naturally communicates to it a certain degree of hardness, combined with the relative plasticity of the matrix itself. The same compound dissolved, owing to the introduction of carbon into the molecule, behaves like a body of small atomic volume, according to the law of Roberts-Austen, *hindering* the molecular transformation of the iron, and maintaining the metal in the condition of β ; from which results the general or partial hardness of the whole, according to the proportions of chromium and carbon, and the diffusion more or less regularly of the compound in question.

It now remains to isolate this compound of chromium, iron, and carbon by chemical means; but this appears to present great difficulties, as it is more or less attacked by all the reagents which have been hitherto tried. However that may be, the behaviour of the chromium does not stand alone when considered from the chemical point of view; for many bodies combine with iron alone, or with the iron carbide and form definite compounds, which may be either dissolved in the mass of iron, or separated as free constituents, when the alloyed body is present in sufficiently large proportions. The solutions of salts in water behave in exactly the same way, and as much may be said of metals dissolved in one another, as shown in the valuable researches of Heycock and Neville, and those of Professor Roberts-Austen. One of the peculiarities attaching to the history of chromium is the property which this metal possesses of remaining free or combining with carbon, so passing from the class of bodies with high atomic volume to the class of bodies with small atomic volume.

It is difficult to foresee where the peculiarities which we have

been engaged in examining will find new practical applications, but it appears to be evident that the scientific study of chromium steel, together with its mechanical properties, would introduce a greater degree of regularity and certainty in its manufacture.

MELTING-POINT OF FERRO-CHROMIUMS.

As the Le Chatelier couple should have been injured by the melted metal, I have endeavoured to determine approximately the melting points by indirect way.

I heat the empty tube furnace up to a *fixed* temperature, which is determined by the bare couple. I then introduce into the tube, and at the place where the couple was situated, the fragment of metal to be examined at the end of an iron wire, and watch what takes place through a blue glass. If the metal does not run, I withdraw it, raise the temperature, and begin again. The process is obviously a rough one, but it enables one to obtain a first approximation, which is of some value. The following results are obtained :—

Ferro-chromium D at 44 per cent. of chromium—

At 1355° C. the metal runs a little in contact with the iron wire, the iron lowering the point of fusion, but it is quite a local fusion.

At 1395° ditto.

At 1445° fusion.

The melting-point is therefore between 1395° and 1445°, and, according to the course of the experiments, nearer to the one temperature than to the other—that is to say, somewhere about 1430°.

Ferro-chromium 66 per cent. of chromium—

1440° shows small drops of metal appearing.

1450° shows larger drops, and a change of form begins.

1475° the metal is pasty and much altered in shape, but it is not yet really melted.

It is thus plain that ferro-chromium undergoes liquation into two parts, one fusible below 1440°, and another more refractory. I have not been able to heat it above 1475°.

MIUM-ST

G LOAD, ELONG AND HARDNESS TESTS

UNANNEALED

this Table are plott

Amount of Stretch in Inches at Elastic Limit.		And T in.	Welding Tests.	Relative Hardness, determined by Professor Turner, in Flat Bar, $\frac{1}{2}$ in. \times $\frac{1}{2}$ in.	REMARKS.
Unannealed.	Annealed.				
0052	...				Comparative tests— Lead . . . 1 Copper . . . 8 Softest iron . 15 Mild steel . . 21 Very hard white iron . 72
...	0063	ble			
0060	...		Would not weld.	22	
...	0089	ble			
0053	...				
...	0043	ble			

Family of notations

(The results given in this Table are plotted on Diagram II.)

	Per Cent.				Limit of Elasticity in Tons per sq. inch.	Breaking Load in Tons per sq. inch.	Extension per Cent. on 2 inches.	Reduction of Area per Cent.	Bending Test of Annealed Forged Bars.	Remarks.
	U.	St.	Al.	Cr.						
St. steel A	.14	.24	...	...	15.17	25.00	37.55	60.74	Bent double cold	
Al. steel A	.13	...	.38	...	20.00	26.00	40.35	60.74	Bent double cold	
Cr. steel B	.16	...	...	.29	17.00	25.00	45.55	65.90	Bent double cold	
St. steel B	.18	.73	...	...	19.00	29.50	34.02	52.66	Bent double cold	
Al. steel C	.18	...	.66	...	18.00	27.00	33.00	52.14	Bent double cold	
Cr. steel E	.12	...	...	.84	19.00	28.00	42.50	61.20	Bent double cold	
St. steel C	.19	1.60	...	...	25.00	33.00	35.10	54.52	Bent double cold	
Al. steel F	.21	...	1.60	...	13.00	26.00	36.35	67.00	Bent double cold	
Cr. steel G	.21	...	...	1.51	19.00	33.50	38.07	55.88	Bent double cold	
St. steel D	.20	2.18	...	...	25.50	34.00	36.50	59.96	Bent double cold	
Al. steel H	.24	...	2.24	...	18.50	28.50	33.00	48.62	Bent double cold	
Cr. steel H	.39	...	...	2.34	24.50	44.00	24.50	33.84	Bent double cold	
St. steel H	.26	5.53	...	...	25.00	25.00	0.37	2.00	Would not bend	Carbon in chrome sample too high to make direct comparison.
Al. steel I	.22	...	5.60	...	27.00	36.00	6.45	6.16	16" broken	
Cr. steel J	.77	...	...	5.19	20.00	55.00	8.20	6.88	Bent double cold	

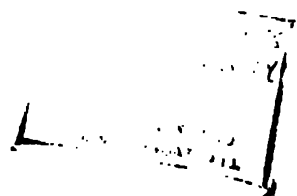




















TABLE 111. *Bending Tests of Cast and Forged Chromium Steel Bars in the Annealed and Unannealed Condition.*

Series and Mark referred to in Paper.	Cr. per Cent.	CAST.		FORGED.		Remarks.
		Unannealed.	Annealed.	Unannealed.	Annealed.	
		Size of Bar, 6" x 1" x 1/2".		Size of Bar, 4 1/2" x 1 1/2" x 1/2".		
1176 A	.22	Did not run.	Bent double.	Bent double.	Bent double.	
1176 B	.29	93° broken.	Bent double.	Bent double.	Bent double.	
1176 C	.48	161° broken.	193° broken.	Bent double.	Bent double.	
1176 D	.57	142° broken.	Bent double.	Bent double.	Bent double.	
1176 E	.84	130° broken.	77° broken.	Bent double.	Bent double.	
1176 F	1.18	50° broken.	76° broken.	Bent double.	Bent double.	
1176 G	1.51	15° broken.	Bent double.	Bent double.	Bent double.	
1176 H	2.54	90° broken.	21° broken.	Nil broken.	Bent double.	
1176 I	3.17	3° broken.	90° broken.	Nil broken.	Bent double.	
1176 J	5.19	Nil broken.	3° broken.	3° broken.	Bent double.	
1176 K	6.89	Nil broken.	3° broken.	Nil broken.	Bent double.	
1176 L	9.18	3° broken.	3° broken.	48° broken.	Bent double.	
1176 M	11.13	3° broken.	Nil broken.	24° broken.	14° broken.	
1176 N	15.12	4° broken.	Nil broken.	Not forged.	Not forged.	
1176 O	16.74	Nil broken.	Nil broken.	Not forged.	Not forged.	

13

1

(This table gives the results of tests on specimens of 1176.)

Series and Mark referred to in Paper.	C. per Cent.	Gr. per Cent.	Treatment.	Total load in Tons per sq. in. on each Specimen.	Diameter before being Tested.	Diameter after being Tested.	Length before being Tested.	Reduction in length per Cent. after being Tested.	Dotted lines show specimen before being tested. Full lines show specimen after being tested.	
										
1176 A .	.07	.22	Unannealed	100	.7983	1.2292	1.0043	53.60		
1176 C .	.15	.48	Unannealed	100	.7981	1.1830	1.0016	50.50		
1176 E .	.12	.84	Unannealed	100	.7980	1.1680	1.0020	48.20		
1176 G .	.21	1.51	Unannealed	100	.7980	1.1157	1.0031	44.60		
1176 H .	.39	2.54	Unannealed	100	.7986	.9825	1.0033	29.50		
1176 J .	.77	5.19	Unannealed	100	.7985	.8580	1.0040	11.15		
1176 K .	.86	6.89	Unannealed	100	.7980	.8793	1.0027	14.40		
1176 M .	1.27	11.13	Unannealed	100	.7980	.9039	1.0009	19.18		

Handwritten signature or mark.



TABLE VI.—*Experiments with Chromium Steel Ring, Mark 1176 L.*
(71 C. 9·18 Cr. per Cent.)

By Dr. HOPKINSON.

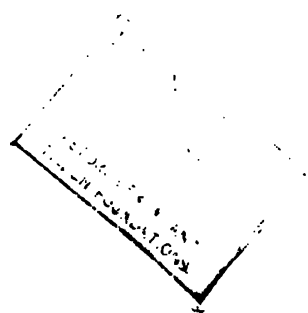
(These results are plotted in Figs. 14 and 15, Diagram VI.)

Before Heating.		After Heating to 850° C. and Cooling Down.		Magnetising Force = 1 02.		Magnetising Force = 4 04.		Magnetising Force = 11 2.		Magnetising Force = 27 06.	
Magne- tising Force.	Induc- tion per sq. cm.	Magne- tising Force.	Induc- tion per sq. cm.	Tempe- rature C.	Induc- tion per sq. cm.	Tempe- rature C.	Induc- tion per sq. cm.	Tempe- rature C.	Induc- tion per sq. cm.	Tempe- rature C.	Induc- tion per sq. cm.
0·018	0·75	0·017	1·5	Deg		Deg.		Deg.		Deg.	
0·037	0·87	0·035	2·75	395	31	416	113	438	340	436	832
0·075	1·53	0·07	5·0	558	41	576	177(?)	584	661	616	2,891
0·15	2·74	0·14	10·25	640	98	645	416	661	2,226	677	7,796
0·30	5·2	0·28	20·2	701	161	717	603	735	5,489	746	8,728
0·60	12·4	0·56	40·0	773	201	789	1,022	807	6,424	813	7,112
1·02	23·4	1·16	86·0	821	249	823	1,462	829	4,943	834	5,375
2·04	45·4	2·23	166	839	331	841	1,863	860	0	860	0
4·04	93·1	4·05	323	860	0	860	0				
7·25	168	7·25	594								
11·86	286	11·72	1,070								
17·4	449	17·44	2,247								
22·78	603	22·7	7,580								
27·06	740	26·6	10,216								
33·24	978	31·67	11,553								

TABLE VII.—*Specific Resistances of Chromium Steel Wires.*

By Dr. HOPKINSON.

Mark.	Analysis per Cent.		As Received.		After Annealing.		After Hardening in Water.	
	C.	Cr.	Diam.	Spec. Resist- ance.	Diam.	Spec. Resist- ance.	Diam.	Spec. Resist- ance.
			Cm.		Cm.		Cm.	
B . .	16	29	0·0925	0·00002234	0·0922	0·00001917	0·0914	0·00001903
F . .	27	1·18	0·0972	0·00003351	0·0981	0·00003305	0·0997	0·00005706
J . .	77	5·19	0·0973	0·00002012	0·0975	0·00002234	0·0991	0·00004062
L . .	71	9·18	0·0982	0·00002315	0·0971	0·00002401	0·0985	0·00002843



Bending Properties, also upon its Hardness.

Filing Report.	Remarks.
<p>ild. stiffer. still. like No. 2.</p> <p>ild. " harder. erably harder.</p> <p>the same as 1176 B. stiffer.</p> <p>still, but could touch file.</p> <p>rather stiffer than C. " "</p> <p>than 1176 C. only just scratch with " "</p> <p>arder still.</p> <p>uch harder than G. ot touch with file. " " " "</p> <p>iff. ot touch with file. " " " "</p> <p>rd. ot file at all. y sufficient to make trips, so tested on et and lowest heats. he same as No. 1.</p>	<p>A sample of this steel, 1½ in. dia- meter, heated to welding heat and quenched in cold water, stiffened a little, but not much, and was easily filed.</p>

Filing tests were made with specially good files,

100

TABLE IX.—To see the Effect of Heat Treatment on Four Samples of Chromium Steel, $1\frac{1}{2}$ in. diameter \times 3 in. long.

(Each Sample was raised to a welding heat and cooled in air.)

Sample.	Analysis per Cent.		Results.
	C.	Cr.	
B	·16	·29	Fracture was similar to that of the steel before treatment, and no increase in hardness was noticed.
F	·27	1·18	
J	·77	5·19	The sample was changed from its comparatively soft nature into one that could not be filed. In other words, the steel showed "self-hardening" properties, that is, became hard without the usual water-quenching process.
L	·71	9·18	
			Do. do.

Note.—The results from J and L were confirmed independently by M. Osmond, who gives full details in the report accompanying his paper.

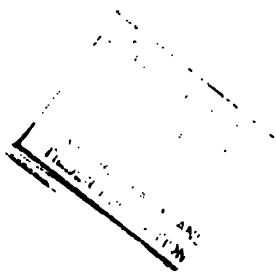
It must be borne in mind that the samples were comparatively small in size, bars of larger dimensions would probably not cool sufficiently quickly to give this hardness.

TABLE X.—Welding Tests of Chromium Steel on Bars
 $\frac{1}{2}$ in. wide \times $\frac{1}{4}$ in. thick.

Sample.	Analysis per Cent.		Results.
	C.	Cr.	
B	·16	·29	Heated to welding heat, but no adhesion.
B	·16	·29	Heated to welding heat with sand, but no adhesion.
L	·71	9·18	The same results as with Sample B.

TABLE XI.—Specific Gravities of Chromium Steel and Ferro-Chromium.

Sample.		Analysis per Cent.		Specific Gravity.
		C.	Cr.	
Steel	A	·07	·22	7·777
	D	·14	·57	7·759
	G	·21	1·51	7·740
	J	·77	5·19	7·712
	M	1·27	11·13	7·675
	O	2·12	16·74	7·595
Chromium pig-iron		4·00	8·30	7·597
Ferro-chromium		5·00	28·00	6·954
"		6·00	44·00	6·814
"		6·47	66·00	7·000



so of Steel and Pig Iron.

Remarks.

but not completely fused.

Osmond states that this was not the actual melting-point, but he was unable to carry this particular temperature sufficiently high. He states that carbon steel containing 70 per cent. carbon, being the same percentage as L, would melt at about 1420°. If this is so, chromium has therefore lowered the fusion-point about 80°. The writer, however, is inclined to think from the behaviour noted when melting the chromium steels described in this paper, that the actual point where liquefaction occurs is about 1400° C.

showed slight appearance of fusion where in contact with the wire of the couple.

no fusion occurred.

metallic drops visible.

drops and slight deformation.

and considerably deformed. Strictly speaking the sample was not melted. M. Osmond considers that this ferro-chromium liquates into two portions, one of which is fusible below 1440° the other much more refractory; hence the sample passes through the pasty stage.

not melted or deformed in the slightest degree.

melts easily and rapidly at the temperature given. Osmond states, however, that this experiment was a doubtful one.

temperatures and analyses are by M. H. Le Chatelier. The information is of great value, hitherto we have been almost entirely uninformed upon this important question.

$1 \cdot 80 + 32 = \text{temperature Fahrenheit.}$

the Le Chatelier pyrometer.

has a much more prolonged stage of pastiness,

Experimental Alloys.

Commercial Alloys.

Cr.	Remarks.
17.00	Supplied as metallic chromium. This material was supplied in fine powder. After being kept some weeks it became green in colour. It was supplied as 96 per cent. Cr.
60.00	
4.24	
27.07	
54.63	
76.88	
78.93	
86.60	
75.60	
...	
6.29	
6.55	
6.5	
6.32	
25.30	
23.00	
...	
44.80	
57.96	
60.35	
62.70	
64.50	
64.80	
7.00	
7.00	
16.00	
30.00	
43.00	
48.20	
50.00	
71.50	
80.00	
82.00	
84.00	
...	
65.87	
6.18	
20.17	
30.10	
30.20	
31.25	

1

TABLE XIV.—*Mechanical Tests upon Chromium Steel by M. Brustlein and others.*
(These Samples were Exhibited at the Paris Exhibition 1889.)

Number.	Analysis.*	Treatment.	Elastic Limit, Tons per sq. in.	Tensile Strength, Tons per sq. in.	Elongation per Cent. in 7.9 in.	Reduction of Area per Cent.	Remarks.
1 A	...	{ Tested in natural state, that is, cooled slowly } { after forging. }	...	70.0	9.5	54.5(?)	There is probably some error in the figures given under "Reduction of area." They are given as calculated in the report referred to.
1 B	...	{ Quenched in oil from a low yellow heat and } { slightly reheated. }	68.0	88.8	8.0	43.0(?)	
1 C	...	{ Oil-quenched as No. 1 B, but reheated to } { dull redness and cooled slowly. }	28.3	46.6	19.5	63.0	
2 A	...	{ Tested in natural state, that is, cooled slowly } { after forging. }	28.8	48.7	18.3	59.0(?)	
2 B	...	{ Quenched in oil from a low yellow heat and } { slightly reheated. }	...	87.2	6.0	30.5(?)	Ditto.
2 C	...	{ Oil-quenched as No. 2 B, but reheated to } { dull redness and cooled slowly. }	53.0	60.7	13.0	58.1	
3 A	...	{ Tested in natural state, that is, cooled slowly } { after forging. }	24.8	41.7	22.5	38.5	
3 B	...	{ Quenched in oil from a low yellow heat and } { slightly reheated. }	...	95.0	0.5	Nil	
3 C	...	{ Oil-quenched as No. 3 B, but reheated to } { dull redness and cooled slowly. }	48.7	55.6	6.0	17.5	
4 A	...	{ Tested in natural state, that is, cooled slowly } { after forging. }	24.8	42.1	24.5	50.5	

YAK AND
LOCATIONS.

ched in Water.

Torsions.	Bends over $\frac{1}{4}$ in. Radius.	Remarks.
...	...	It will be noticed that "A" to "E" contain about the same percentages of carbon, but of different qualities.
...	...	
...	...	"A" to "E," when quenched in water or oil, were, owing to their hardness, crushed by the clamps of the testing-machine, consequently no reliable tensile test could be obtained. "F," being of much milder temper, was not injured by this treatment.
...	...	
...	...	
...	...	
...	...	
...	8	Quite soft in water and oil.
...	...	Breaks rotten; will harden neither in water nor oil.
1	1	Hardens well in water and oil.
7	4	Just hardens in water; feels rotten and not hardened in oil.

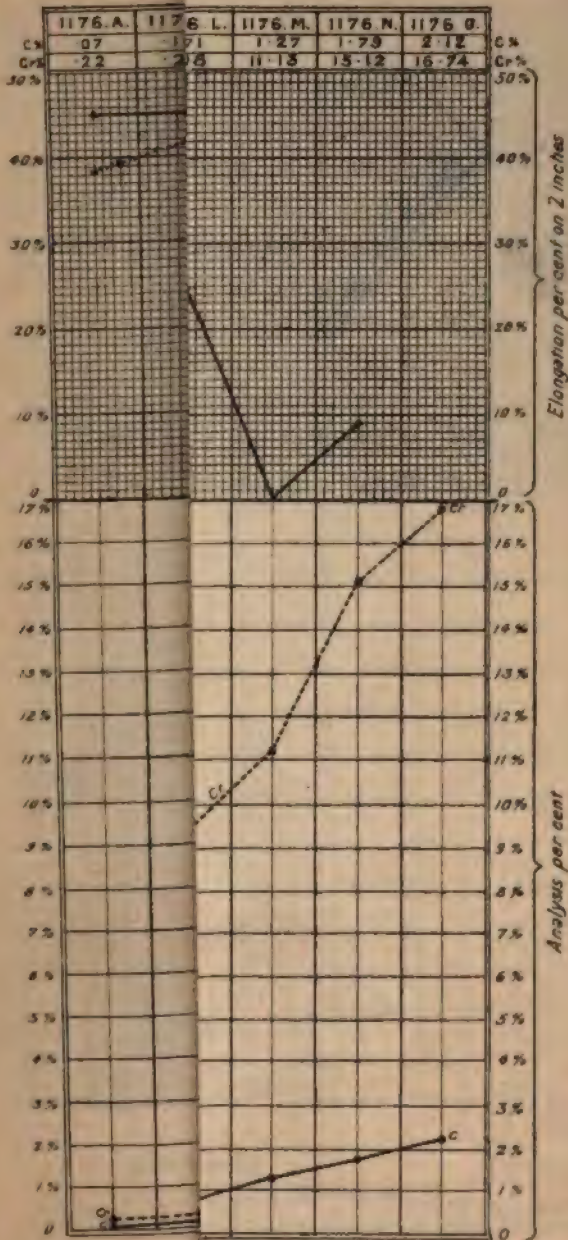
field.

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M STEEL.

PLATE I

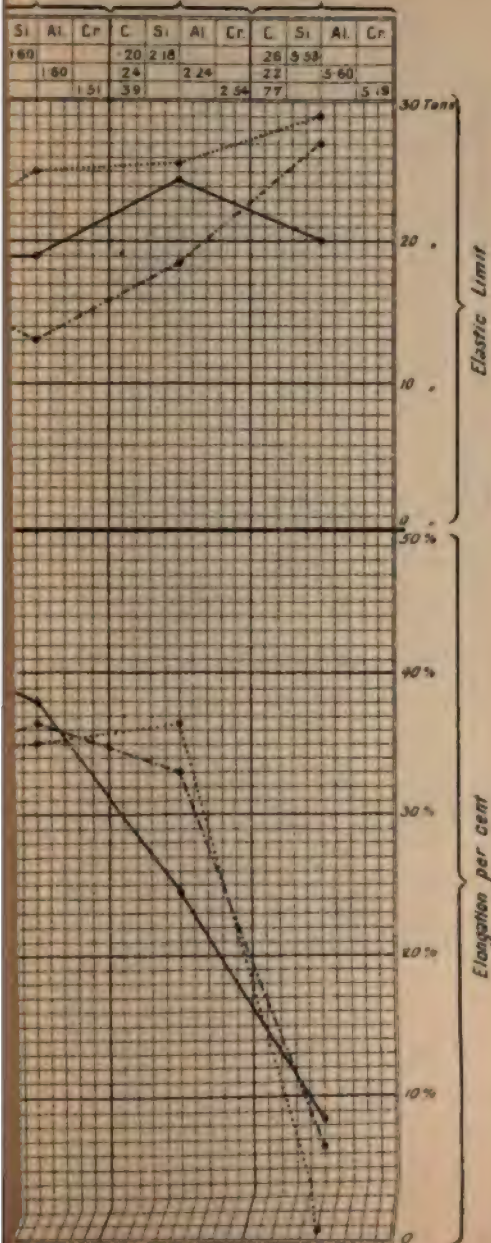
nit, Elongation,
chromium Steel p



Ballantyne, Hanson & Co Edinburgh & London.

PLATE II.

1 Chromium, Silicon,
annealed.



Dism, Silicon, and

e III., and Aluminium
S & SL, Vol. II., 1889 ;

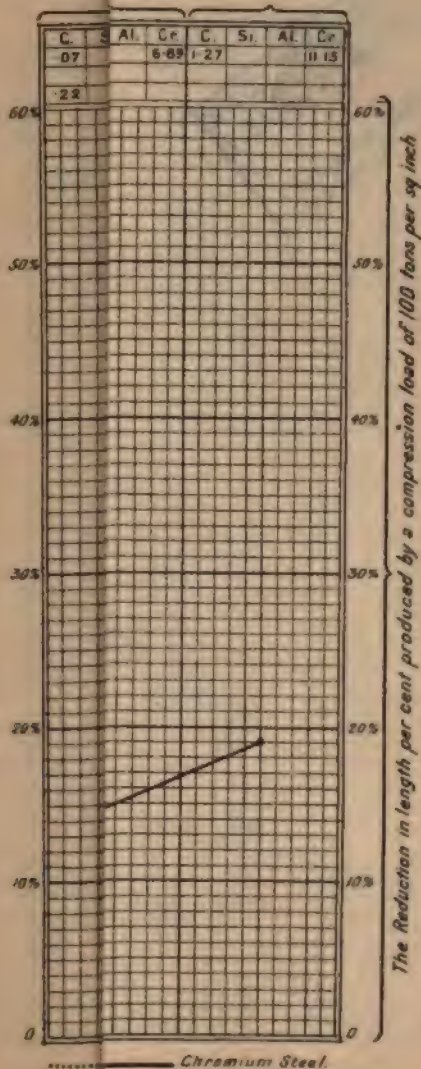
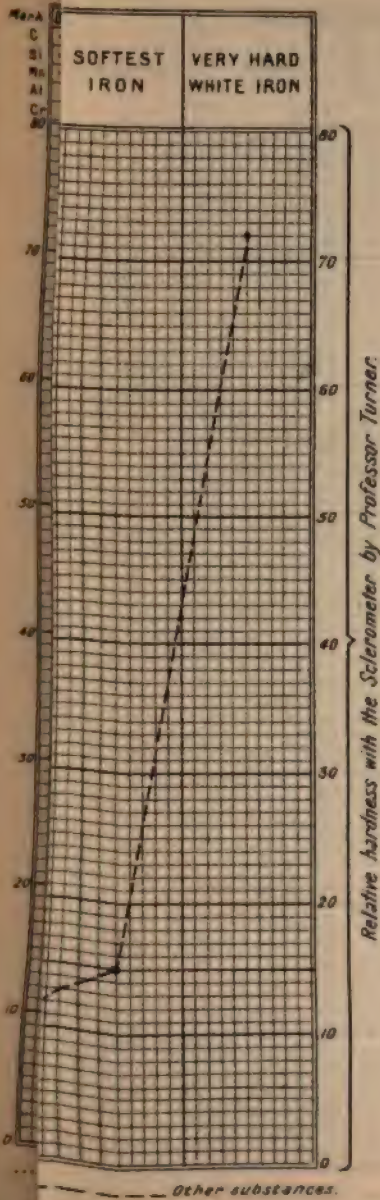




PLATE IV

els.



1. 1. 1.

2. 2. 2.

3.

4.

PLATE V.



ty = 1950 feet per second.
= 34,280 foot tons.
on = $36\frac{1}{2}$ inches of steel and iron.











Printed by the Government of India
at the Government Press, Calcutta

PLATE VIII



Presented by the Hon. Mr. Justice







Fig. 8.

Range, 80 yards.

Velocity, 1825 feet per second.

Energy, 2250 foot tons.



No. 2.

STEEL PROJECTILES after each has penetrated a
 10" Plate and 8 feet of Oak Backing.

The two Projectiles after each has penetrated the
 Plates and 8 feet of Oak Backing represented in

after firing, '01" in diameter.

" "013" "

17. (1000)

1898

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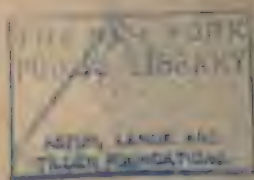


Fig. 11.



ROUND ARMOUR PLATE penetrated by Four Hadfield's
inch Chromium Steel Projectiles.

1911



CHROMIUM STEEL.

PLATE XIV.

Fig. 12.



Compound ARMOUR PLATE penetrated by Four Hadfield's
6-Inch Chromium Steel Projectiles.

CHROMIUM STEEL.

PLATE XV.

Fig. 13.

Range, 20 yards.

Striking Velocity, 1830 feet per second.

Energy, 2300 foot tons.



Compound Armour Plate penetrated by Four
6-inch 6-Inch Chromium Steel Projectiles.

Projectiles were uninjured, and if they had been fired with
velocity as used at the Annapolis trial (2075 feet per
second) they would probably have penetrated uninjured a
Compound Plate.

OMIUM STEEL.

Fig.14

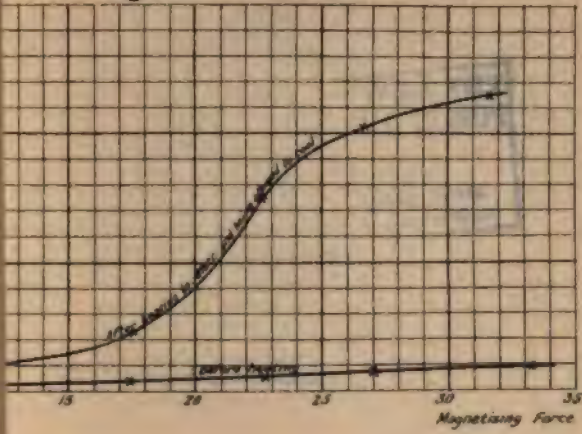
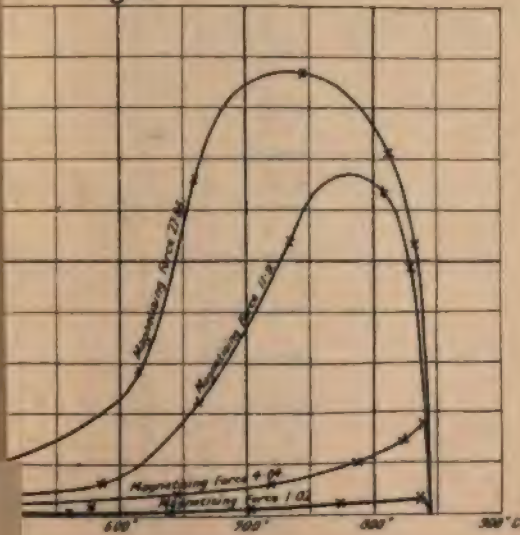


Fig.15



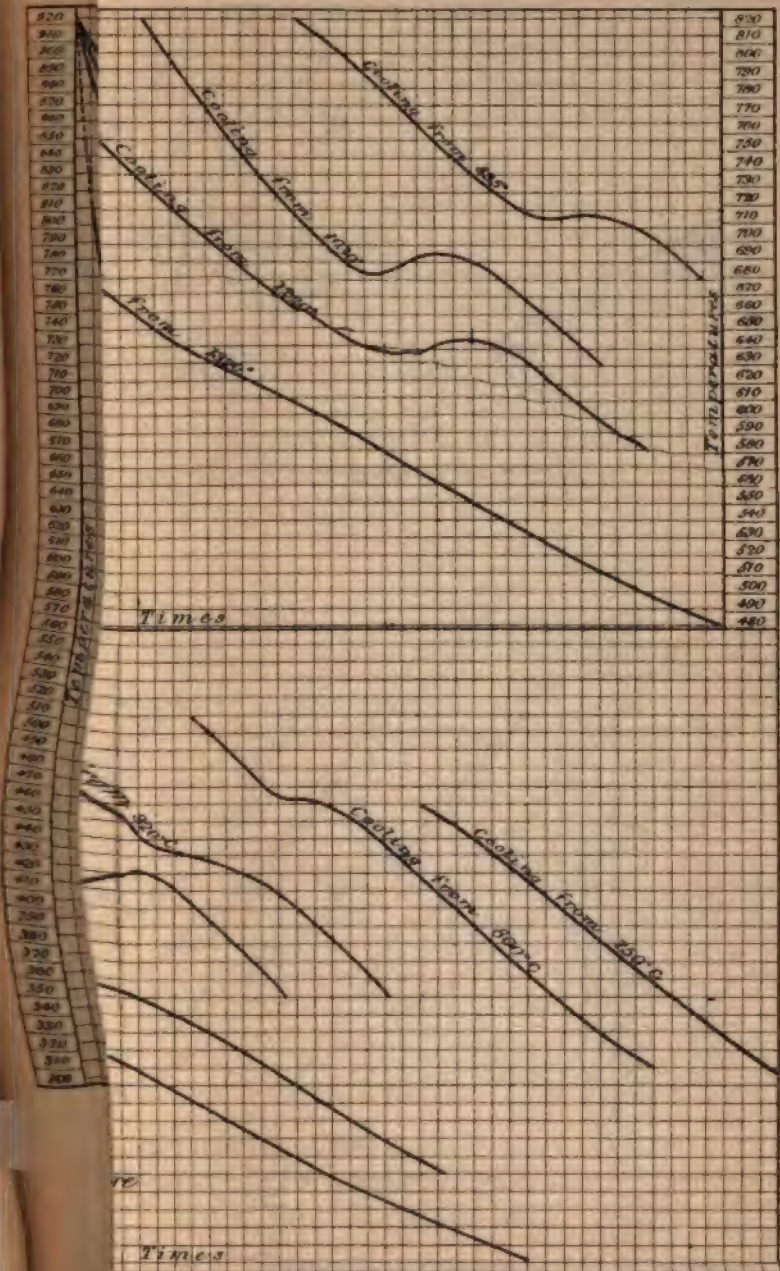
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Figure 17.
ing M. Osmond's Report.



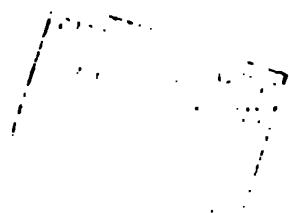
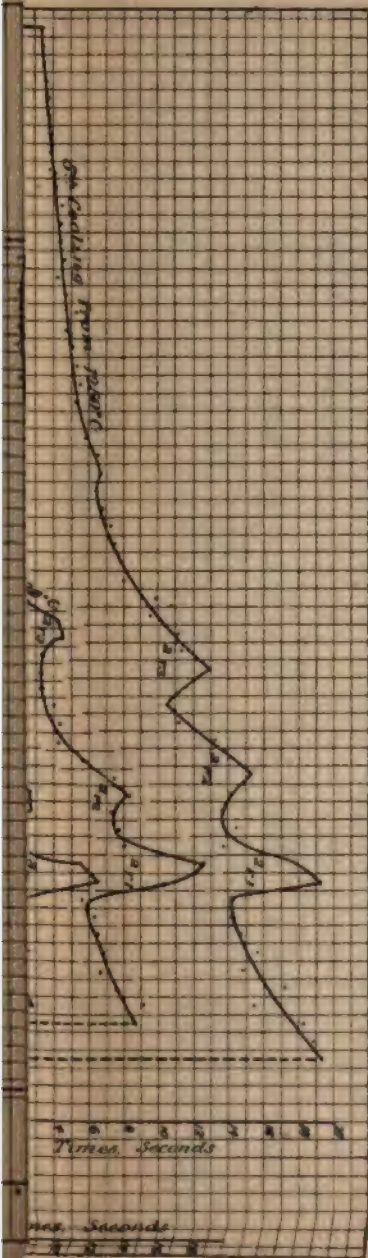


PLATE XVIII.

1176 (C.15 Cr 488)
Influence of the initial temperature and of the rate of cooling.

Scales
 $10^{\circ}\text{C} - 1 \text{ Sec.} = 5 \text{ mm.}$



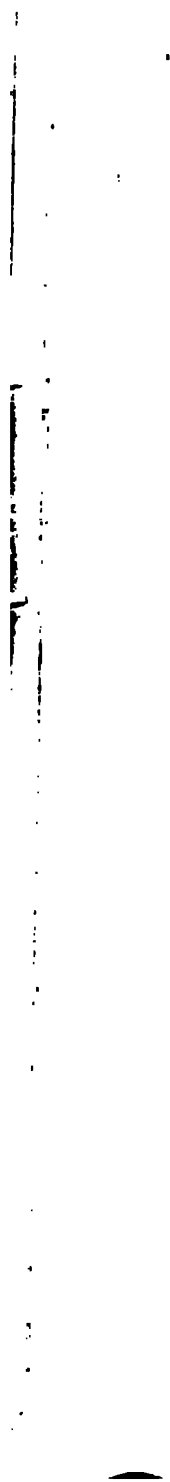


PLATE XIX

Magnified Linear.

80

300

80

45

45

Hampered

Annealed at

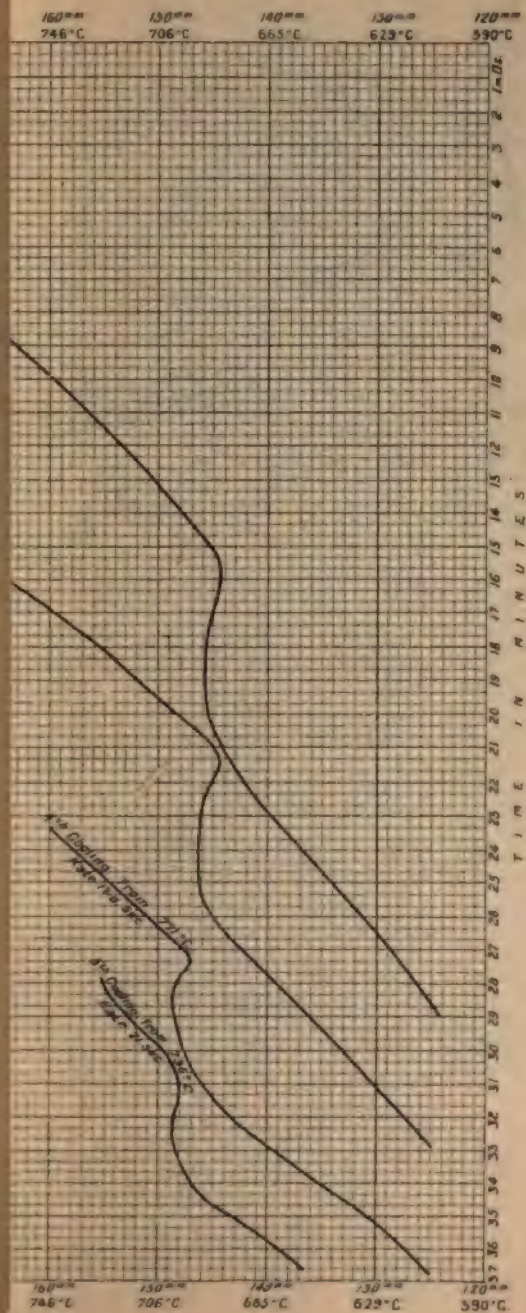
Annealed at

Annealed at 1820° C.



L."

PLATE XX.



1. The first part of the document is a list of names and dates.

2.

Ferro-chromium 90 per cent.—

At 1485° this alloy does not run, or even soften.

Sample A, sold to Mr. Hadfield as pure chromium, melts rapidly when introduced into the furnace at 1465°. This metal is very far from being pure chromium, as the subsequent analysis has shown. The sample is very small, very porous, and the experiment was of little value.

The liquation of ferro-chromium at 66 per cent. is an interesting fact—a similar effect having been observed in the case of phosphoric pig iron, and even, but not so distinctly, in the case of pure grey pig, and reminds us, to some extent, of the experiments made by Professor Roberts-Austen * on alloys of gold and aluminium. In this case, the refractory compound dissolves in the more fusible compound, so that it may be said that there is no longer any definite point of fusion, but the metal passes through a pasty condition more or less prolonged between the liquid and the solid condition.

* *Proceedings of the Royal Society*, vol. xlix. p. 347.

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1822.	Mar.	Paper.	"Philosophical Transactions," pp. 253 to 270.	Faraday and Stoddart.	"Alloys of Ste
1823.	...	Papers.	"Annales de Chimie," vol. xvii. p. 55. Second communication, p. 194.	M. P. Berthier.	"Sur les Alliages du Chrome le Fer et l'Acier."
1857.	June	Paper.	"Comptes Rendus," vol. xlv. p. 632.	Frémy.	"Blast Furnaces of Oxid Chromium Metallic Iron
1864.	...	Book.	...	Dr. Percy.	"Iron and Steel (p. 185).
1877.	...	Paper.	Institution of Civil Engineers, vol. liii. 1877.	G. Rolland.	"Note on Chromium Steel" (excer
1877.	...	Note.	"Proceedings of Iron and Steel Institute," vol. i. 1887, p. 231. (Published in "Chemical News.")	Sergius Kern.	"Chromium Steel Cast Ste
1877.	...	Paper.	Iron and Steel Institute.	Dr. Riley.	"Pig Iron made by the Taama Iron Co."
1877.	Dec.	Book.	"Metallurgical Review," part i.	...	"Chromium Steel
1886.	...	Paper.	Iron and Steel Institute, vol. ii. 1886.	A. Brustlein.	"Chromium Iron and Steel
1886.	...	Note.	Translated from "Annales de Chimie et de Physique," 5th series, vol. xv.	Boussingault.	"Production, constitution, and properties of Chromium Steel."
1889.	...	Paper.	Congrès International des Mines et de la Metallurgie.	A. Brustlein.	"Le Ferro-Chrom

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month.	Nature of Notice.	Where Given.	Author.	Title.
Oct.	Paper.	"Franklin Institute Journal."	F. Lenwood Garrison.	"The Metallurgical Arts at the Paris Exhibition, 1890."
...	Book.	...	H. M. Howe.	"Metallurgy of Steel" (contains an excellent résumé of the metal chromium and its application to steel.)
May.	Presidential Address.	Iron and Steel Institute.	Sir F. Abel.	Reference to Chrome Ore.
Feb.	...	"Journal of Society of Chemical Industry."	J. E. Glatzel.	"Preparation of Chromium."
...	Book.	...	A. Vosmaer.	"The Mechanical and other Properties of Iron and Steel."
Jan.	Paper.	"Journal of the Stevens Institute of Technology" (Hoboken, N. J., U.S.A.), vol. ix. No. I.	Hart and Calisch.	"Chrome Steel, its Manufacture and Uses," with complete chemical analyses.
...	Book.	...	A. Brustlein.	"The Metals at the Paris International Exhibition of 1878," pp. 159 to 162. (Exhibits of Holtzer & Co.)

DISCUSSION.

The PRESIDENT said that Mr. Hadfield had left M. Osmond's report, which was appended to his paper, to be dealt with by Professor Roberts-Austen. He therefore invited that gentleman to speak before the discussion commenced. Professor Roberts-Austen and M. Osmond had, he understood, been making experiments in a parallel direction with several of those alloys, and it would be interesting to have those results before them.

Professor ROBERTS-AUSTEN said that it was quite unnecessary that he should bear testimony to the admirable character of the work, which was a continuation of that which Mr. Hadfield had conducted for so many years, or refer to its extreme scientific importance, quite apart from the very great industrial interest which it possessed. He ventured to claim many of the results which Mr. Hadfield had obtained as confirmation of the views which had been put forward at such considerable length by M. Osmond, and which had been sustained by himself. Many of them thought that iron was capable of existing in at least two distinct forms, the α and the β forms; and if they were right in that respect, it explained many of the anomalies which were met with in the thermal treatment of iron.

Without going into the matter at great length, the members of the Institute would remember that, as a mass of carburised iron or steel cooled down, there were at least two distinct evolutions of heat which marked its cooling. The one occurred at a temperature of about 850° C., and it was thought by M. Osmond that this evolution of heat was due to a molecular change in the iron itself. The second main evolution of heat occurred at a temperature that was variable, but near 650° , and was due to a change in the relation between the carbon and the iron. The presence of carbon, in fact, appeared to enable the hard variety of iron which existed at a high temperature to be maintained, if the carburised iron were rapidly cooled and quenched in water or mercury—in fact, hardened.

Now, what did they find when they came to examine the

particularly interesting series of alloys which Mr. Hadfield had placed at their disposal? They found one of the most remarkable facts that he thought had been brought before them for many years. If the initial temperature of the cooling of those remarkable alloys was high, there was no true recalescence at all. If the initial temperature of the alloy was as high as 1300° , it was found on cooling that there was an absolute continuous curve (as shown in the diagram Professor Roberts-Austen drew on the black-board); but if the initial temperature of cooling were comparatively low, say 900° , there was distinct recalescence—a distinct evolution of heat at the point at which the carbon change took place.

M. Osmond had stated that in his report, and he (Professor Roberts-Austen), working quite independently (for he had not seen the report until it was placed in his hand just before the meeting), absolutely confirmed his observation. M. Osmond worked with the chromograph, and he (Professor Roberts-Austen) with the recording instrument, similar to the one described on the previous day, but a more elaborate one, and he quite confirmed M. Osmond's results. He now placed in the hands of the President a low temperature curve with distinct evolution of heat, and a high temperature curve with none at all. What was the probable explanation? It might be that at the high temperature of 1300° the iron existed entirely in the hard β form, and that slow cooling in the presence of chromium did not enable the hard variety of iron to change into the soft variety. There was the remarkable fact that slowly-cooled alloys, especially "J" and "L," were hard when the mass was slowly cooled. That would seem to prove that the hard modification of iron was maintained when slowly cooled—not rapidly, as in ordinary hardening, and, consequently that iron was maintained in the hard modification right to the end.

He thought, however, that it was more likely that a triple compound of iron, chromium, and carbon present was formed, that the chromium was removed from the sphere of its ordinary action, and that they really had a chromium-carbon compound, behaving very much as carbon would alone. The formation and the subsequent action of this triple compound would depend, in great measure, on the initial temperature to which the mass of

metal containing it was raised. Of course the explanation was more or less incomplete, because they had only just begun to examine that most interesting product; but he wished it to be remembered that whereas all the varieties of carbon steel with which they were acquainted showed recalescence—a remarkable evolution of heat—chromium-steel showed none at all, if the initial temperature of cooling were high. He desired to renew his thanks to Mr. Hadfield, and to express the hope that he would long continue his admirable series of researches.

The PRESIDENT said they would listen with interest to any observations that members might have to make upon the interesting results obtained by Mr. Hadfield, and also those by Professor Roberts-Austen and M. Osmond. He must confess that while admiring the ingenuity of Professor Roberts-Austen's explanation with regard to the remarkable behaviour of chromium alloys when cooled down from a very high temperature, and while he himself could not at the moment suggest any other, it was scarcely satisfactory or conclusive to his mind.

Professor ROBERTS-AUSTEN said that he had only offered the explanation in a tentative way, after conducting a series of experiments which were necessarily few, as the time at his disposal between receiving the paper and its being read at the meeting was very limited.

Mr. T. E. VICKERS said that he thought the members ought to be much indebted to Mr. Hadfield for this continuation of his papers on chromium-steel. The experiments which he (Mr. Vickers) had made in chrome very much confirmed those of Mr. Hadfield. The great difficulty in making trials with chrome-steel was the difficulty of getting chromium without carbon. It was difficult to know whether the hardening results obtained were due to carbon or to chromium, and it would therefore be desirable if a purer chromium could be obtained. At present, however, he did not see any great chance of obtaining it. The manufacture of chromium-steel in large masses in the open-hearth furnace was very great, owing to the great liability of chromium to oxidise. It was exceedingly difficult to get any quantity of chromium to

combine, unless there was a large quantity of carbon present. The moment the carbon was eliminated from the charge, the chromium seemed to vanish also. So far the experiments which he had made in the open-hearth furnace had not been satisfactory, except with small percentages of chromium; but with crucible steel it had long been found that it was a very great advantage in obtaining a very hard and durable steel for tools.

He did not agree with what Mr. Hadfield had said with reference to the use of steel in the hardened and in the unhardened state. Mr. Hadfield thought that steel for guns and machinery should be made hard by carbon, and that it should be used in the natural, and not in the hardened state. He (Mr. Vickers) had always contended, and should continue to do so until he had good proof to the contrary, that steel was both tougher and harder in the hardened state. In gun-work, for example, he believed that the material should be hardened either in oil or in water, and then tempered. Years ago, he commenced experiments in oil-hardening, and obtained exceedingly satisfactory results. In their own works, it was found in the case of the piston-rods of steam-hammers that in hammering steel the strain on these rods was so great that no unhardened steel rods would last over a comparatively short period. For the last twelve or fifteen years, they had always used their piston-rods in the hardened state, and they had always found the result very satisfactory. He mentioned this as one of many instances of hardening that would be of interest to the members.

He thought Mr. Hadfield might be wrong in attributing cases of hardness in some of his experiments to hammer-hardening. It was well known that ordinary steel did become hammer-hardened, but it was not always the same with alloys. He found many which were softer when hammered at a low heat than they were when annealed after hammering. He gave the results of one series of trials of a hammered bar of steel alloy under various kinds of treatment:—

1. In hammered state	76 tons per square inch.
2. Annealed	82 " "
3. Hardened in oil at 1500° and reheated to 900°	91 " "
4. " " " 1200°	60 " "
5. " " " 1500°	80 " "

He drew attention to the fact that the annealed condition was harder than the original, and that the softest was the one reheated to 1200° , after being hardened at 1500° . These results being rather extraordinary, he repeated them, and obtained the same result. Perhaps Professor Roberts-Austen could explain some of the results.

Professor ROBERTS-AUSTEN asked how much chromium there was in the alloy?

Mr. VICKERS said that he had forgotten the exact amount, but he believed that it was something over 1 per cent.

Professor ROBERTS-AUSTEN asked what was the quantity of carbon?

Mr. VICKERS said it was very difficult to get at the amount of carbon. With alloys the determination of the quantity of carbon was exceedingly difficult. No carbon was added to the alloy, and it therefore contained only what was in the materials of which it was composed.

Mr. GALBRAITH asked Professor Roberts-Austen if he had attempted to show the recalcence to which he had referred in the case of steel when hardened, *i.e.*, in the act of being hardened? He would explain what he meant. If a piece of steel were quenched at a high temperature, it would be found that the specific gravity fell very considerably, compared with what it would do if it was cooled slowly. That was a point that would have a considerable influence in explaining the hardness of steel if the recalcence disappeared or could be shown. Of course, the rapidity of the thing might be in the way; but, no doubt, the matter had attracted Professor Roberts-Austen's attention.

The PRESIDENT said he thought the members would be interested in hearing what Dr. Anderson had to say on the subject of elastic limit, which was dealt with by Mr. Hadfield in the course of his paper.

Dr. ANDERSON, F.R.S., said that unfortunately he had had no opportunity of studying the paper beforehand, and the subject was a rather tough one to deal with without some little preparation. The question of chromium steel had given them some little trouble at the Royal Arsenal. As Mr. Hadfield had stated that there was some difficulty in mixing the chromium with the mass of steel, even on the small scale on which he appeared to have operated, he should like to ask him whether he thought that on a large scale—in the open-hearth, for instance, where castings of many tons weight were made—the difficulty would not be greatly accentuated, and whether the steel produced would have different quantities of chromium in different portions? He did not mean by way of liquation in cooling; but in cases where a small quantity of chromium was added to a large mass, was there any certainty that it would diffuse itself uniformly through the mass, and so produce a uniform material?

In the Arsenal there had been recently a case of failure of a very large forging—a gun-hoop of chromium-steel—the chromium, he believed, having got in accidentally. The walls of the hoop were about 6 inches thick, and it cracked spontaneously internally. The mass had been oil-hardened in the usual way, and about an hour after having been taken cold out of the oil, a loud report was heard. When, after several months delay, the hoop was put into the lathe, a second report was heard. Ultimately*the hoop was cut in two, and broken under the steam-hammer, and then there appeared an enormous crack about 4 feet long and 4 inches wide, which had developed inside the walls of the hoop. Of course, the treatment of steel in small masses, and its treatment in very large ones, were two totally different things. They did not know what took place within the mass, nor the extent of the severe internal stresses—so severe as to produce the effect which he had just mentioned.

It was only on the previous day that Professor Roberts-Austen had shown him some recent experiments which demonstrated that steel cooling under compression appeared to behave in a different manner from what it did when it was cooled in its ordinary free state. In fact, the point of recalescence seemed to disappear, so that in addition to the stresses set up by the cooling of large masses, there was a total change in the structure

of the steel, which was a consequence of it, and the effect of which it was impossible, at present, to gauge, but which manifestly still further complicated the problem of the employment of steel in large masses. Mr. Hadfield advocated the using of steel of naturally high quality, high elastic limit, and high ultimate strength, instead of depending upon the qualities communicated by hardening—a proposition with which Mr. Vickers appeared to disagree. He thought that no general rule could be laid down. When using wire, for instance, which was now so largely employed in the manufacture of guns, they might have a steel of naturally high quality, and use it with safety, because of the smallness of the individual mass, and the certainty that every portion was of the required strength, and in the most advantageous state of tension. As far as he could see, it was impossible to burst a gun reinforced by means of wire. The steel being of a naturally high quality, perhaps three times the strength of ordinary steel in large masses, although hardened, was, for the reasons he had just given, perfectly safe, even under the sudden stresses caused by the discharge of cannon. They had tried firing a tube split longitudinally, and merely held together by moulding with wire, and, so far, repeated firing had only resulted in a burst of gas through a portion of the wire. He was going to carry the experiment still further, to see to what degree of tenuity the wire-winding might be carried so as to produce a burst. The same sort of steel, used in large masses, would, he was convinced, be exceedingly dangerous, because they were entirely ignorant of the condition of the inside of the mass of steel. It was certain that even steel of low carbon, of moderate tensile strength, and of great ultimate extension, would, when burst by explosives, fly into little bits, and break more like glass than like what might be expected from the tough material indicated by the test-pieces. A gun might pass proof, and be apparently perfect, and yet be in a highly dangerous state; and they might have what had happened over and over again—guns that had been many years in the service ultimately bursting under a reduced charge. Those cases were, in his opinion, only to be explained by the theory that the steel had always been in a state verging on destruction—that firing had

gradually extended the internal mischief till the gun failed ultimately with a moderate charge.

The question, therefore, as to the quality of steel which should be used depended very greatly upon the masses in which it was required and the subsequent treatment to which it was to be exposed. If the steel, after casting, was always kept in a condition in which it was not exposed to such severe internal stresses, they might be quite safe in using it; but if they went through the critical operation of hardening, mischief might be done which no amount of annealing could afterwards repair. If a fracture existed, it was impossible to do away with it, and even its existence was, from the nature of the case, undiscoverable. A specimen taken after treatment might show that the steel had been much benefited; yet, as they could not see what was inside the steel, they might have done tremendous mischief and be wholly ignorant of it, thinking all the time that the treatment had greatly improved the mechanical qualities of the material. That was one of the reasons why, in building the great guns now required, it was much better to rely for radial strength on wire, than on steel, however excellent, in large masses.

MR. F. W. WEBB (London and North-Western Railway), at the request of the President, said he would state the result of his experience in the use of chrome steel, which he had been using for many years. He had found that the springs made of chrome steel were superior to those made of ordinary spring steel. He was gradually removing all the springs used on locomotives and tenders on the North-Western Railway, and replacing them by springs of chrome steel; they were also using the same quality for the waggon department. He had used chrome steel for tyres, and he had found that he could get a much better wearing tyre with chrome steel than without it. He had also used the same material for tool-steel, and he had found that with only 0.65 of carbon he had a steel that would stand twice as long as any other that he could use; so much so, that he had now tools which had been in the lathe two days turning steel axles without any lubrication, and without taking them out of the rest to grind them. He had tried a good many other experiments, but he was

not able at present to give the results; he should be happy, however, to do so at some future time.

Mr. W. F. BEARDSHAW said that for some years he had been engaged in the manufacture of an alloy of chromium with carbon steel, and he could confirm what Mr. Webb had stated as to the results obtained.

Mr. E. H. SANITER asked Mr. Hadfield whether, during his investigations of the effect of chromium on iron, he had noticed whether chromium had the same desulphurising effect on iron as manganese had.

The PRESIDENT said that M. Osmond had stated in his report that he had arrived at the conclusion that chromium existed in at least three different forms: in the state of dissolved chromium; in the state of a compound of iron chromium and carbon, in the form of isolated globules; and also in similar combinations in the form of a solidified solution. In view of what had been stated, and confirmed by Dr. Anderson, with regard to the difficult fusibility of the ferro-chromium alloys, and the great difficulty in uniformly diffusing it through a mass of metal, he should like to ask whether it might not be possible that at any rate the second form to which M. Osmond referred might be the original ferro-chrome disseminated in a fine state of division through the mass of the particular specimen examined? Perhaps, also, the author, when answering the question, would state what was the proportion of chromium in the projectiles which resisted fracture on impact in such a remarkable way when fired against 9-inch plates.

Professor ROBERTS-AUSTEN said, in reply to Mr. Galbraith, that he thought the experiment he had suggested would be very difficult. A skilful physicist, by placing steel in a calorimeter, might, he thought, obtain the evidence required. Moissan had, by distilling amalgams of chromium, obtained an allotropic, or at least an "active" form of it. He hoped that a few more experiments would enable him (Professor Roberts-Austen) to bring forward a theory that would satisfy the President, who,

he hoped, would not demur to the view that the material was a very sensitive one to molecular change, and that the nature of the change depended greatly upon the temperature to which the mass was raised. The relations of the chromium and the carbon (quite apart from the iron in the mass) were not the same if the initial temperature of the mass was high as they were if the initial temperature of the cooling mass was low.

Mr. R. A. HADFIELD, in reply, said that Mr. Vickers had asked whether chromium could be alloyed with steel in large masses, as he thought that there must be a certain amount of oxidation. He (Mr. Hadfield) could not agree with him on that point. Of course, the addition would require to be carefully made, and it should also be added in a molten form, so as to get a thorough admixture; but otherwise he thought that it would be quite possible to make chromium steel in any sized ingots required, and get a uniform composition, in the same way as with ordinary carbon steel. With reference to the use of harder steel with higher tensility, Mr. Vickers had stated that he preferred softer steel, and to oil-harden it. It appeared to him that it could not make much difference with regard to the actual final result. If they took milder steel, with a tensility of say 28 tons, and a permanent set-point of 15 or 16 tons, and if they oil-hardened it, and raised the tensility to 38 or 40 tons, and increased the permanent set-point to 18 or 20 tons, he could not see that there should be much difference in the actual result from that of taking hard steel of the same tensility and permanent set-point to commence with. It appeared that in whatever way they oil-tempered or toughened steel of any temper but that known as mild, if they took it in a heated condition, and dipped it into a cold medium, they must to some extent set up a strain. For that reason he would call special attention to the remarks of Mr. Kreuzpointner, who had ably summed up this question. He said it was much better to take a material free from strain with natural hardness, and not induced hardness. Mr. Vickers had referred to his (Mr. Hadfield's) remarks on hammer-hardening. Of course he had only made the remarks as applying specially to the particular alloy under consideration—chromium steel. Chromium had, without doubt, a very strong influence upon the carbon present, and he thought

that if Mr. Vickers took similar samples, and if he worked them at a comparatively low heat, he would always retain the hammer-hardening. In other words, they obtained a similar effect to that of plunging it into a cooling medium. What he had said with regard to producing steel on a large scale, in reply to Mr. Vickers, would also apply to Dr. Anderson's observations. He could not see the difficulty of getting a thoroughly uniform alloy on a large scale. Those who were at Paris on the occasion of the last Exhibition would have noticed Messrs. Holtzer's exhibit of large chromium steel ingots, about 18 inches square. In the conversation which he had with Mr. Brustlein, the metallurgical expert of this firm, he had never heard that he had had any difficulty in producing chromium steel of a uniform composition. Besides that, in England they had had large projectiles made for the 13·5-inch, and also for the 16-inch guns. Large ingots were required to produce such projectiles, and he was not aware that there had been any want of uniformity in the material. It was simply a question of manipulation. The special point to be borne in mind was to make the additions in a fluid state, so as to get a thorough mixture. He thought there would be no difficulty in that case in obtaining large masses of chromium steel of a uniform composition. He was pleased to hear the remarks of Mr. Webb, which only confirmed what he had himself in view in writing the paper. If in this country they wished to keep to the front, they would have to pay special attention to the alloys of steel. On the Continent far more attention was being given to the subject, and if Englishmen could not see their way to devote more time to that class of work, he was afraid that they would suffer to some extent. He knew for an absolute fact that large quantities of alloyed steel were being made abroad, and one of his objects in writing the paper was to call attention to that subject. He knew that French makers especially were doing a large amount of work in special alloy steel for tyres and other purposes. He was therefore glad to hear Mr. Webb speak so favourably of his own experience of chromium steel. Mr. Saniter had asked whether chromium would desulphurise? That was certainly not the case. He had had ferro-chromium containing 10 or 12 per cent. of chromium, and as much as 0·3 per cent. of sulphur, which proved that chromium did not act as a

desulphurising agent. With reference to the President's question as to chromium existing in three forms, he was sorry that he was not in a position to answer it more clearly. Professor Roberts-Austen had paid so much attention to that special point—the existence of metals in more than one form—that he would leave him to reply upon that subject. As far as he could see, he did not think that it did exist in more than one form. He thought that, as in the case of tungsten, silicon, and aluminium steel, there was only one form. With regard to carbon, the case was, of course, very different. He did not think that chromium acted *per se*, but he thought that it had some indirect influence in causing a more intimate combination of iron and carbon, and for that reason there was a stronger action when they wanted to produce a hardened steel. As to whether chromium was disseminated throughout the mass in a sort of independent and not combined form, he was inclined to think with Sir Frederick Abel that that was possibly the case, and it rather agreed with the observation he had just made, namely, that the combination of carbon and iron was perhaps only indirectly effected by the chromium. He was very much obliged for the kind attention they had given to the paper, and he hoped they might have more discussion in a written form, as the true object of the paper was to call forth discussion on the matter.

The PRESIDENT said they were very grateful to Mr. Hadfield for having brought so valuable a paper before the Institute, for the trouble he had taken in its elaboration, and for the time he had devoted to the careful examination of the behaviour of the alloys of iron with chromium. It was very important that capable men, who had large resources as manufacturers at their disposal, should carry out researches under conditions closely approximating to those which actually occurred in practice, which chemists found it very difficult to accomplish in the laboratory. It was but too frequent that chemists' results were, and naturally, mistrusted by manufacturers, because they considered that a laboratory experiment was one thing, and an experiment in a works another. Mr. Hadfield happily combined within himself the resources and knowledge of a scientific chemist and expert investigator with those of a manufacturer,

and he thought they ought, rightly and justly, to expect great things from men like Mr. Hadfield. He was accomplishing very promising work, and should be encouraged as much as possible to pursue the course of work which he had followed with so much success within the last few years. On behalf of the Institute, he thanked Mr. Hadfield most cordially for his paper.

CORRESPONDENCE.

Professor LEDEBUR, of the Freiberg School of Mines, sends the following communication:—

It is, in my opinion, a rule of general application, that by alloying a metal with another element, its hardness, its limit of elasticity, and its tensile strength may be raised to a certain extent. The toughness is, however, invariably diminished. By the addition of the weaker, but softer, tin to copper, its tenacity and hardness are very considerably increased; but the alloy is much more brittle than pure copper. Plumbiferous tin is harder, and has a greater tensile strength than pure tin, as long as the percentage of lead does not exceed a certain limit. Alloys of gold and silver, either alone or with copper, are distinctly harder and stronger, but less tough than the pure metals. Of this behaviour of the metals, as is well known, frequent use is made, if it is required to obtain for one purpose or another a material characterised either by its hardness or its tenacity when subjected to a dead load. The unavoidable increase in brittleness by alloying always, however, imposes a limit when the finished object is required to be subjected to vibration. For this reason, I am unwilling to accept Mr. Hadfield's view that the special question of steel alloys or combinations will be the means of eventually enabling our civil and mechanical engineers to design and carry out works of a magnitude which at present are not possible. The more we increase the tenacity of iron by alloying it, the more its brittleness increases. Works of magnitude, however, necessitate the use of a material with as little brittleness as possible.

The extent of the influence exercised by various elements on one and the same metal may be somewhat variable, and it cannot be denied that one element is remarkable for increasing the hardness and tenacity, whilst another is remarkable for increasing the brittleness. We know that even small amounts of carbon are sufficient to exert marked influences on the properties of iron. We know, however, that such influences are dependent on the state in which the carbon exists, and that phosphorus, while as a rule slightly increasing the tenacity, very greatly increases the brittleness. Mr. Hadfield's former investigations have shown us that this law is applicable to alloys of iron with silicon, manganese, and aluminium, although the action of these elements is much weaker than that of carbon. The experiments now described show that the same conditions obtain in the case of chromium. Chromium steel (E), with 0.84 per cent. of chromium and 0.12 per cent. of carbon, possesses a higher limit of elasticity, greater tensile strength, and greater hardness, than does chromium steel (B) with 0.29 per cent. of chromium and 0.16 per cent. of carbon; but its elongation and its reduction of area, as determined in the tensile tests, and its resistance to bending after having been quenched in water, are less; it is, in fact, more brittle. The extent of this influence exerted by chromium is considerably less in an iron poor in carbon than has hitherto been usually assumed.

If a third element enters into the composition of the alloy, the changes brought about in its physical properties are not in accordance with the sum of the influences which each of the two foreign elements exerts, but it is usually, or indeed always, greater. Hence, for example, the melting-point of an alloy found experimentally is lower than the calculated temperature of fusion, and the greater the number of foreign constituents, the lower the melting-point becomes. Thus, by the addition of bismuth to lead-tin alloys, the melting-point may be lowered to about 100° C., and by the further addition of cadmium, to about 70° C. Mr. Hadfield deserves the credit of having definitely proved that this law also holds good for the other properties of metals, and that it is thus possible by the addition of chromium to impart to high carbon steel a degree of hardness and tensile strength which could not be attained by the presence of

carbon alone nor of chromium alone. In my opinion, therefore, the chief use of chromium steel, and of other steel alloys, must in the future be sought in this direction—that is to say, in their applications as material characterised by resistance to mechanical wear and to change of form. Chromium steel projectiles penetrate thick armour-plates without being broken up, the mechanical action of the impact being in this case utilised in bringing about a change of form in the softer armour-plate, and the hard projectile remaining intact in spite of its brittleness.

On such subjects as those I have alluded to, Mr. Hadfield's arduous researches have afforded us information of inestimable value.

Dr. E. J. BALL drew attention to the observation of M. Osmond, that certain specimens, when heated to temperatures of about 1300°C ., retained their hardened condition, even after slow cooling; that "annealing produced the ordinary effects of hardening." This would appear to agree with some observations he had made, and published in a paper read before the Institute, which tended to show that, at the temperature mentioned above, iron very low in carbon undergoes a change in its physical condition, passing into a "harder" form.

With regard to the tensile tests, it would be of interest to know whether chromium steel, hardened from different temperatures, acts like some of the higher carbon steels that have been examined in the metallurgical laboratory at the School of Mines. A gradual increase in tenacity was observed as the temperature from which the hardening was effected rose, but at a temperature of about 900°C . there was a first maximum tensile strength, the tenacity greatly diminishing within the next 100° , and then increasing again with equal rapidity as soon as this temperature was exceeded. Perhaps Mr. Hadfield, in continuing his most interesting examination of the chromium iron alloys, may be able to give further information on this point.

Mr. T. BLAIR: My experience of chrome steel, extending over some years, is that, although a valuable material when properly treated, it has acquired a reputation for uncertainty and treachery.

mainly owing to unskilful manipulation, and the great variation in the composition of the materials used in its production.

In the first place, the alloy, or *chromeisen*, is of exceedingly irregular composition, especially that made in crucibles. On looking through a large number of analyses, published and from private sources, I find—

Carbon may vary from	1.0 to 11 per cent.
Silicon " " " " " "	0.5 " 8 "
Manganese " " " " " "	trace " 4 "

while the sulphur and phosphorus are invariably very low. It is not to be expected that uniform results can be obtained when each 50 or 60 lbs. (or one crucible melt) varies within these limits.

My experimental meltings have been mainly made by using such crude alloys, purified by Mr. Joseph Bedford's patent process, by fusion of the alloy with oxides. A melt of three tons was made with the following results:—

	Crude Alloy.	Purified Alloy.
	Per Cent.	Per Cent.
Carbon	3.620	2.182
Silicon	2.230	0.093
Sulphur	0.012	0.010
Phosphorus	0.050	0.000
Manganese	2.892	0.951
Chromium	11.000	8.980

The product was well melted, and of uniform composition.

Professor Arnold, of the Sheffield Technical School, kindly made for me an ingot from this calculated to contain 0.70 carbon and 1.00 per cent. chromium, aluminium being added as usual at the end. This steel, hammered down to 1-inch square bar, stood the following tests, also made by Professor Arnold:—

Tensile strain	67.24 tons per square inch.
Elongation on 2 inches	16.00 per cent.
Contraction of area	40.00 "

A portion of this bar was rolled down to No. 5 wire-rod, and gave:—

	1.	2.
Area of rod	0.036	0.040 area in square inches.
Tensile strain	78.7	71.4 tons, area in square inches.
Elongation	6.2	6.2 per cent.
Contraction of area	41.5	52.5 "

My analysis of this steel gave:—

	Per Cent.
Carbon (by combustion)	0.750
Silicon	0.040
Sulphur	0.015
Phosphorus	0.055
Manganese	0.350
Chromium	1.098
Iron (determined)	97.690
	<hr/> 99.998

These excellent results have been repeated by subsequent meltings at various steel-works, and can, without doubt, be regularly produced with due care in melting and subsequent manipulation. The selection of the scrap for melting is of much importance; it must not be taken haphazard, as is only too frequently the case, but should be of uniform quality, as "cut-iron," "dead-soft," &c., of which the chemical composition is known.

Although Mr. Hadfield finds his samples A to G (0.22 to 1.51 per cent. chromium, and 0.07 to 0.27 per cent. carbon) not much superior to silicon or aluminium steel, I venture to point out that the above, with 1.098 per cent. chromium, and 0.75 per cent. carbon, gives results almost identical with his sample I, with 3.17 per cent. chromium, and 0.41 per cent. carbon. So that high tensile strain and high ductility are obtained by either composition. I think the tests A to H would have come out better with higher carbon, had that been his object. The same would also, I think, apply to the hardness tests in Table V.

Out of the numerous meltings I have made since the above, two facts are worthy of note. An ingot with 1.13 per cent. chromium, and 0.60 per cent. carbon, was planed through the centre longitudinally, and a bar 1 inch square cut out; this, tested in the *cast state*, broke in the grip at 60 tons, and another bar cut out in the same way, and from the same ingot, 1½ inches square, and forged down to 1 inch square, also broke in the grip at 72 tons.

Mr. Hadfield, in his paper, says that chromium does not confer soundness. It certainly appears to have done so in one series of instances. Three melts were made at a works in Sheffield for the steel-melter, misunderstanding his instructions,

omitted to put in the aluminium (no spiegel or ferro-manganese being used). The ingots *did not rise* in the moulds, and hammered down well to *solid* bars. Their composition was as follows:—

	1.	2.	3.
Carbon	0.75	0.50	0.60
Silicon	0.16	0.124	0.06
Chromium	1.10	0.538	0.38
Manganese	0.50	1.64	0.49

I have noticed that chrome steel ingots generally pipe well, and are very fairly free from blowholes.

As to welding, I have not been able to do this when any notable percentage of chromium was present, and in no case, even with 2.25 per cent. chromium, could I get any sign of damascening.

Mr. Hadfield's mention of self-hardening chromium steel is very interesting. I have known cases where low percentages of tungsten and chromium have been introduced into magnet steel, but no doubt an excellent self-hardening tool steel could be so produced, and possibly more cheaply, and with more reliability, than is the case in the production of tungsten steel at present.

Certain makers of crucible steel in Sheffield use chrome alloys in their process, believing that the steel is thereby toughened. But in many cases this is done without any knowledge of the composition of the alloy, or of the resulting steel. Of course, there are others who work on scientific principles.

I believe that there is a future for a chrome steel with low carbon. Such a tough steel is badly wanted for wire ropes, bicycle spokes, and sundry other similar materials where high tensile strength and ductility are combined; also in castings. A ferro-chromium, with 1.0 per cent., or less, carbon would be very useful for producing this class of steel.

Mr. Howe, in his book on "The Metallurgy of Steel," says that chrome steel manufacture "is a promising field, but only for those competent to control it scientifically." No class of steel has, in my opinion, suffered more in repute than this, as in all its stages it requires careful and intelligent manipulation, and even the analysis is difficult, especially for carbon and chromium. It is with peculiar pleasure, therefore, that I welcome Mr. Hadfield's paper as an invaluable piece of information on a very little

understood, but deeply interesting and important, branch of the metallurgy of steel.

Mr. F. LYNWOOD GARRISON (Philadelphia) writes as follows:— Inasmuch as it appears practically to be impossible to introduce the chromium into steel by other means than through the medium of an alloy of iron and chromium, we must, in order to cheapen the cost of chromium-steel, produce such ferro-chromium at a very low figure. From the little experience I have had, it has for some time been my impression, and Mr. Hadfield's results appear to confirm it, that the increased hardness which chromium is popularly supposed to impart to steel is due, not so much to the chromium itself, as to the carbon present. Thus, for example, it will be noticed in the following analysis of a Holtzer chromium-steel projectile, that the carbon is quite high and the chromium low; indeed the carbon content approximates to that of Mr. Hadfield's steel containing from 11 to 12 per cent. chromium.

	Point of Projectile. Per Cent.	Body of Projectile. Per Cent.
Silicon	0.322	0.419
Phosphorus	0.011	0.044
Manganese	0.306	...
Chromium	1.69	2.28
Copper	0.121	trace
Carbon	1.32	1.26

Referring to Table VIII of Mr. Hadfield's paper, I note that his steel to which I more particularly refer, 1176 M (C. 1.27 and Cr. 11.13), when simply forged and annealed, "filed hard," and when quenched in cold water, "would not file at all." I therefore judge its physical properties to be very similar in some respects to the steel of which I give the analysis, and that the hardness is due to the carbon, and not to the chromium. Mr. Hadfield states that this particular steel of his "forged very well," had an ultimate tensile strength of 62 tons per square inch, and had an elongation of 10.38 per cent.

I fancy these figures are very much above anything that could be attained with the aforesaid Holtzer steel, and the consequent inference would be that this increased ductility is due to the chromium, which is, say, 2 per cent. in one case, and 12 per cent. in the

If these observations are correct, they confirm Mr. Hadfield's conclusion, as well as my own, that chromium *per se* does not appreciably harden steel. Just what action it has on steel in the absence of carbon, or rather, I should say, in the presence of a very small amount of carbon, it is impossible at present to declare. It would seem obviously necessary, in order to produce a ductile chromium steel, to have the content of carbon in the original ferro-chromium as well as in the chromium steel, as low, and the amount of chromium as high, as possible. All the published analyses (with one exception) of ferro-chromium which I have yet met with show a high content of carbon, the average ratio of the total carbon to the chromium being about 1:6. Some of these alloys contain as much as 12 per cent. carbon and 64 per cent. chromium; in others the proportion is about 1:10. It follows, as a natural consequence, that on using an alloy so high in carbon to produce a chromium steel, a very considerable proportion of this carbon must be absorbed by the steel, resulting in hardness at the expense of ductility.

It seems to me that, in order to produce a ductile alloy, not only of chromium steel, but of nickel or tungsten steel, the ferro alloy from which these compounds are produced should be made with as little carbon as possible in its composition. It is obviously impossible to effect this result in using a carbonaceous material as a reducing agent.

I have been recently following with great interest certain efforts which are being made to produce these ferro alloys, containing little or no carbon, either in the graphitic or combined condition. With what success we have met I will leave you to determine when I present the results before the Institute, which I hope to do within the course of the next few months. I will state at present, however, that the results appear to be entirely satisfactory as far as we have gone. I give below an incomplete analysis of some ferro-chromium which we recently made from a very poor chrome ore:—

Chromium	15.540 per cent.
Carbon	0.972 "
Silicon	0.818 "

By comparing this analysis with those given in Table XIII. of

Mr. Hadfield's paper, it will be observed that the one there given which most nearly approaches the above analysis contains 16 per cent. chromium and 2.72 carbon. I feel quite satisfied, judging from some of our more recent experiments, that by using a richer chrome ore we can obtain a higher content of chromium, and certainly no more, but even less, carbon.

Now, as to the practical application of chromium and other alloyed steels, it seems to me we have reached the stage in the metallurgical arts when mild steel is soon to be replaced, to a very considerable extent, by other compounds, which we may term, if you please, alloyed steels, just as some few years ago mild steel replaced malleable iron. Let us suppose, for the sake of argument, that the ratio of the tensile strength of malleable iron to mild steel will be about 2:3 (*i.e.*, 40,000 is to 60,000 lbs. per square inch), which is equivalent to a gain in strength of the latter of 50 per cent. If we assume the average tensile strength of mild steel, say boiler-plate, to be about 60,000 lbs. per square inch, and that of the steel marked 1176 H on Table I. of Mr. Hadfield's paper to be about 100,000 lbs. per square inch, we have a gain of $66\frac{2}{3}$ per cent. and a ratio of 3:5; the elongation in the case of the mild steel assumed to be 22 per cent., and in the chromium steel 26 per cent., or a gain of over 4 per cent.

We must bear in mind, however, this excellent showing with chromium steel is derived purely from experimental results, and even if it were possible to produce it cheaply enough for commercial purposes, we could hardly expect to reach, at the outset, the above figures. The commercial success of such a commodity will chiefly depend upon the available supply of chrome ore, and the possibility of producing ferro-chromium containing little or no carbon, at a price not much greater, if any, than the present cost of ferro-manganese.

I have been lately making some investigations into the available supply, not only of chrome ore, but of the lesser known ores of tungsten, wolfram, and scheelite, and also of nickel ores. If the information I have received be correct, it would seem that an abundant supply of these ores will be forthcoming as soon as any considerable demand for them is created.

It won't be useless to mention the numerous purposes for

which chromium steel, possessing a greater strength and ductility than the best mild steel, might be used. Every engineer can readily appreciate what great saving of weight would be effected in substituting for structural purposes a material 20 to 25 per cent. stronger and 10 per cent. more elastic than any now in use. It would truly be a boon to naval engineers and constructors. If such a steel as I indicate contained, according to Mr. Hadfield's showing, only from $2\frac{1}{2}$ to 3 per cent. chromium, there is no reason why it could not be made at a very moderate price, provided, as I have intimated, that the practically carbonless ferro-chromium can be made at a low cost.

MR. FRANK W. DODD remarks that the exact rôle played by the third element, chromium, in chromium steel is still left in doubt. It seems to be proved that chromium does not of itself confer hardness, and considering that it exists almost entirely in a dissolved state in one form or another, it could hardly be expected to impart either its hardness or high melting-point to the mass of metal dissolving it. The points of fusion of all the samples seem to have been considerably lowered by the addition of chromium, and, in fact, most of the conditions of solidification and cooling of the steel are modified, as might well be expected when a considerable percentage of a third element is dissolved in it. It might very reasonably be suggested that the chief duty of the chromium consists in bringing about these changes in the point of fusion, and in other critical temperatures of the steel during solidification and cooling, and thereby giving the molecules of the mass an opportunity of arranging themselves in an order different to that obtaining in simple carbon steel. Assuming this to be the case, the most to be expected directly from the chromium is that it will only allow itself, in a state of combination or otherwise, to be dissolved in the mass of the metal without interfering very seriously in questions of strength, ductility, &c., but relying for its influence mainly on its thermal effects. The production of an equable and natural hardness throughout the mass of the metal by an internal agent modifying the conditions of cooling must, in many cases, have great advantages over the production of hardness by a violent interference with the normal cooling of the metal by external means.

Mr. B. H. THWAITE: I wish to congratulate Mr. Hadfield on the masterly and thorough manner in which he has investigated the genesis and influence of the metal chromium as an alloy associated with steel. Mr. Hadfield has already given us monographs on the manganese and aluminium elements as ferrous alloys; but this last monograph is more thorough than the two preceding ones, although they were admirable examples of practical and scientific research. I believe I am partly responsible for suggesting the diagrammatic form by which Mr. Hadfield has so ably and lucidly shown the lessons of his physical researches. For practical men, this diagrammatic method of showing up the results and their meaning by a long and exhaustive series of researches is all that could be desired. It enables him at a glance to absorb the valuable results of the tests. There is a striking difference between the density characteristics of the four ferrous alloying metals—silicon, aluminium, chrome, manganese, nickel, and tungsten.

According to Wurtz, in his *Dictionnaire de Chimie*:—

The density of silicon (graphitoid).	. . .	= 2.49	} Wrought iron, 7.4
" " aluminium for cast metal .	. . .	= 2.50
" " " " forged metal .	. . .	= 2.67
" " chromium, ordinary .	. . .	= 3.00
" " " " crystallised .	. . .	= 6.80
" " manganese .	. . .	= 7.38
" " nickel, cast metal .	. . .	= 8.270 to 8.3
" " " " forged metal .	. . .	= 8.606 to 8.82
" " tungsten	= 0.18	

That there is a striking analogy between the general influence on iron and steel of the alloys of silicon and aluminium is further confirmed by their extraordinary similarity of density.

One striking fact conspicuously brought out by Mr. Hadfield, but already known, is the refractoriness of the metal. Any open-hearth steel furnace that will easily melt this metal must have excellent thermic qualifications. It is, of course, understood that unless there is a perfect and absolutely equal fluidity of the alloying metals, the imperfectly melted one will be merely mechanically shelled or enveloped with the more fluid one. There will be no alloy combination.

It is also obvious that in proportion to the altitude of its fusion temperature will be its tendency to rapid solidification;

and here is the greatest difficulty we have to contend with in dealing with alloying metals having a very high fusion temperature.

The fusion of the metal can be, and is, accomplished, but the rapidity with which it solidifies in the pouring operation, and in running the metal into the moulds, almost absolutely prohibits the possibility of obtaining a soundly solid ingot.

In fact, owing to its rapid solidification at even very high relative temperatures, its tendency will not be so much to confer soundness on any metal it is alloyed with, as to increase the volumetric proportion of the interstitial contraction spaces.

Aluminium and silicon, on the contrary, owing to their lower melting points, and lighter density, remain quite fluid, whilst the steel is in a semi-plastic but presumably porous condition. The result is, that in *pari passu* measure as molecular contraction of the steel occurs, the fluid aluminium or silicon flows into the intermolecular spaces. The result is a soundly solid metallic ingot or casting, but not a homogeneous one. Whereas the addition of chromium will not supply this filling-up metal, of a lower melting point and density, its tendency will be to increase the volume of contraction cavities. If we only exactly knew the fusion temperature of chromium, the exact volumetric addition to the contraction spaces could be calculated.

The addition of aluminium or silicon to ferro-chromium alloys would enable a solid casting to be obtained, but there must of necessity be a very uniform molecular structure.

It would be of the highest value to metallurgical science were an alloy ingot cut up into equal slices, and each slice then carefully divided into small and equable squares, each square being put to analytical and microscopic tests. Such an exhaustive test would throw light on a very obscure surface. A test of this character would remove many doubts, and decide whether the theory I have enunciated many times, in order to explain the cause of unsoundness of ingots, and why alloying metals of a low melting point confer solidity, is the correct one or not.

I quite coincide with Mr. Hadfield in his remarks as to the advisability of the Government adopting the C.G.S. or metric system. The thin end of the wedge would be the introduction in our schools of this metric system as the future standard units and

methods of measurement, placing the ordinary system in a secondary position. The scholar would gradually begin to think and judge of measurements in the metrical manner.

To those already saturated with the existing units and system, the difficulty is in educating one's self to think in metres. One is apt, in mentally taking a measurement, to think in feet, and transform them by mental calculations into metres. If our scholars are educated to do the reverse of this, and think in metres, the necessity for the mental transformation will be gradually extinguished. A set of tables published in the *Engineer* some four years ago, showing the relative values of the two measurements, should be in the hands of every engineer and metallurgist. A constant reference to this table is the best possible system of education for a practical man brought up in the old school.

I am also in the fullest accord with Mr. Hadfield in his remarks anent our adoption of progressive movements and advances. Better that we should enter the way of progress, and maintain the lead in it, than wait until circumstances force us into the path, only to find it too full to enable us to elbow our way to the front.

Mr. A. VOSMAER would like to point out the peculiar hardness of rich ferro-chromes. Professor Behrens showed him a sample of 50 per cent. chromium (ferro-chrome from De Haen, Hanover), possessing a hardness of 7.5, that is, a hardness between those of quartz and topaz, thus indicating a considerable difference between dead-hair steel and chilled iron, the first-named being about 6.5, the latter about 6. There is not so much difficulty in separating the hard compound under the microscope, provided some ferro-chrome be used.

Mr. PAUL KREUZPOINTNER (Altoona, Pa.): It is only from a desire not to appear indifferent to the invitation to discuss Mr. Hadfield's admirable paper on chromium steel that I have accepted the proposal, despite a natural hesitancy, to appear in the metallurgical forum.

Three essential conditions determine the fitness of steel for a given purpose.

First.—Freedom from oxides, slag, blowholes, or any defects which tend to impair the continuity of the structure, and that most intimate adhesion of the individual particles which alone impart to a metal maximum cohesion or the power to resist rupture.

Second.—The degree of difference existing in the nature of the two bodies, which, as is now recognised by many high authorities, make up the mass of steel, the crystalline and supposed harder portion, and the amorphous or supposed softer portion; this degree of difference in hardness or softness of the respective bodies, and the predominance of one over the other, determining the "wear and tear" of steel to a great extent.

Third.—The hardness or softness of the individual particles of steel; the degree of hardness determining the greater or less resistance of each individual particle or molecule to crushing and change of form, through hammering, rolling, or other mechanical agencies.

Permit me to consider briefly the effects of the three conditions named on the behaviour of steel.

The evil effects of blowholes and foreign matter, which impair the continuity of the structure of steel, are so well known to the readers of the *Journal of the Iron and Steel Institute* that nothing further need be said here.

Of the second condition named—the relative difference of hardness or softness of the two bodies forming the steel—we have as yet no tangible measure wherein this difference consists, though that there is a difference we can see on the previously smooth surface of the test section of a broken or bent test-piece, even if there were no other indications. That the predominance of the soft or amorphous body or "matrix," as M. Osmond happily terms it, or *vice versa*, has a good deal to do with the behaviour of the steel, other things being equal, can hardly be denied by even the superficial observer.

The crystals, their hardness and number, evidently give strength and elasticity to steel, and if the crystals are wanting we have a metal of low strength and high ductility; the metal will "set" and "flow" easily under this condition.

On the other hand, if the hardness of the matrix approaches that of the crystals, without, however, assuming the character of

the latter, then we have a stiffer metal with still good ductility. In this case the crystalline portion of steel, in its efforts to resist rupture, receives greater support from the amorphous portion with a resulting higher resilience, comparative with the ultimate strength of the two metals. When the matrix is very soft, there appears to be maximum local contraction; where the matrix is harder, there seems to be a more uniform stretching all over with the same ultimate strength, and total, or even greater elongation.

Carrying this analogy to the extreme, we may imagine a steel entirely devoid of crystals in the ordinary sense of the word, and all amorphous, yet possessing the greatest hardness, giving the porcelain fracture of tungsten steel.

If, in that case, brittleness would not be produced by the combination of chemical elements, then a product is conceivable, possessing maximum elasticity with great strength, and still a fair degree of ductility.

An approach to this ideal condition we observe in very fine grained carbon or special steels. It need hardly be mentioned that a prime requisite to attain such an ideal is freedom of the steel from all foreign matter which would impair continuity of structure, and perfectly uniform distribution of all chemical elements through the mass.

Now let me attempt to explain the third condition named above. Often we find two pieces of steel of the same class, having the same, or nearly the same, ultimate strength and elongation, to be structurally different. If nothing else, the surfaces of the test-pieces after rupture indicate such difference. Various indications make this very noticeable to the expert.

It is obvious that there must be an inherent difference in structure to produce such results.

The surface of the test-section of one broken piece appears creased, while the other presents a velvety appearance. The fractures of the section also show a difference, though not always pronounced.

In the one case the crystals evidently were crushed by the stress applied; in the other case they were not. If both the crystals and matrix are soft, we have the so-called "mushy" steel. If the crystals are soft, but the matrix comparatively hard, we have a steel of comparatively high ultimate strength,

but inferior resilience and "staying" power. If the crystals are hard and large, and the matrix soft, we get the creased appearance of the surface of the test-piece. If both crystals and matrix are too hard, we have a brittle metal. If the crystals are hard and very small, and the matrix comparatively soft, we may expect, from all we know about steel, a metal of high elasticity and good elongation. We may call all this mere speculation, if you please, and in a measure it is speculative, because we are unable to give quantitative proof of the conditions described. But before denouncing it all as worthless speculation, we have to deny certain everyday facts, which are observed by those who have the opportunity to test and examine large masses of steel of various grades. The conditions described represent the ordinary carbon steels of the market in their natural state or condition, and leave out of consideration the effects of hardening, tempering, and annealing.

Now, then, what are the characteristics of chromium steel in comparison with carbon steel?

In its most favourable results obtained thus far chromium steel possesses great hardness, with high elasticity and a fair degree of ductility. It is said to be quite forgeable, with the exercise of proper care. As a commercial product, however, it has thus far not gained that wide field of application it once promised to occupy, and, with the exception of the St. Louis and Illinois bridges, its usefulness has been confined to a few special purposes. The reasons would seem to be twofold: in the difficulty to produce steel containing a uniform percentage of chromium, and in the fact that, as Mr. Hadfield points out, chromium without the presence of carbon does not impart hardness to iron. Only with a given percentage of carbon, and a comparatively high percentage of chromium, do its qualities become pronounced, and different from carbon steel.

Mr. H. Howe, in his "Metallurgy of Steel," states that the uncertainty of finding chromium in uniform percentages in chromium steel has been one of its drawbacks, so far, though he expresses the belief that with the exercise of skill, care, and intelligence this difficulty can be overcome. Indeed, it would seem that M. Holtzer in France, and Mr. Hadfield in England, have already attained considerable perfection in this direction. Mr.

Hadfield himself admits that chromium is very refractory, and requires a very high heat to incorporate it with the iron.

If we examine chromium steel from the standpoint of a commercial product, we find that, according to Mr. Hadfield's statement, it is out of the race with carbon steel until the chromium reaches a given per cent., 0.75 to 1 per cent.

As to the item of cost of production, being no doubt more expensive than common carbon steel, it must, in many cases at least, be a question with the consumer whether chromium steel possesses such superiority for a given purpose as to warrant an extra outlay. At this stage of our inquiry it is well to take into consideration one point, which it seems to the writer has often been overlooked in the use of steel—namely, that steel suitable for one purpose is not necessarily the most successful metal for another similar purpose.

The ideal steel is the one which, with the required strength, combines a sufficiently high degree of natural elasticity not to suffer deformation or "set" under maximum strains, and yet possesses sufficient ductility to prevent rupture under most trying circumstances.

In addition to these ideal requirements there must be such perfect uniformity of chemical elements in the steel, continuity of structure, and adhesion of the individual particles as to prevent rupture or shearing along the sides of the crystals, rather than to crush them. Now, since it is difficult, in every day practice, to attain this ideal, the next best thing must be sought, and a steel must be obtained suitable for any given purpose.

Steel has often received an unwarranted setback on account of the belief that, because it gave so many thousand pounds ultimate tensile strength per cent. of elongation or contraction of area, it is the best metal required. Steel cannot be thus forced into the straight jacket of a mathematical rule and formula. Whenever the conviction is universal among engineers that steel, though a most excellent metal, wants to be studied closely and intelligently, and not with the sole aid of the calculus and a few tensile tests—which method of ascertaining quality has been very much overrated, valuable though it is—and by calling to our assistance in this peculiar work, knowledge, patience, judgment and sound reasoning, then steel will be used with

proper discrimination and qualification to the advantage of the consumer. With this fundamental principle for the use of steel as a guide, the writer takes the liberty to say that, because chromium steel has proved so remarkably successful as a material for projectiles, it would be like jumping at conclusions to say, that therefore chromium steel must be the proper metal for every other purpose. The skill required in its production, the care necessary to forge the metal, are factors which have a certain significance when we propose to use chromium steel for structural and railroad material. We know now, from the experiments of eminent physical metallurgists, and the important object-lessons taught by "detail" fractures of steel structures, that the frequent application of small stresses, just passing the elastic limit, is much more destructive to structural material than a few heavy blows which must apparently break the structure at once. Hence the fact that chromium steel, withstanding the tremendous blow of piercing an armour-plate, however thick, does not warrant us to conclude at once that this steel would, with equal success, resist the insidious effects of the innumerable and variable blows, small though they may be, which a tyre, an axle, or any similar structure has to stand.

In a solid and compact mass, like a projectile, the presence of a segregation, want of uniformity of structure, or a small vein or nest of oxides, is not necessarily a cause of weakness during the instantaneous strain of compression when the projectile strikes the armour, and when, for a moment, all the molecules are crowded upon one another, and are surrounded closely, during their passage, by the metal of the armour, which thus acts as a retaining ring, as it were. The same steel, with the same small defect, rolled into an axle, tyre, or girder, &c., and subjected to continued hammering and straining, will sooner or later become "fatigued" at this weak point, and either break suddenly, or crack, or break in "detail," presenting the anomaly of having pierced a 14-inch armour "without a scratch," but failing in the performance of—to the superficial observer—mathematically lighter duties. Now the writer does not by any means wish to detract from the merits of chromium steel; on the contrary, from all he knows about it, personal and otherwise, he must acknowledge its superiority in many respects, and he believes, with Mr. Howe, that there is a

future in store for the steel. But he would consider it something like a breach of trust to the metallurgical world were he not to call attention to certain factors which, in the use of steel for various purposes, tend so strongly to enforce the law of the survival of the fittest. From the microscopic examination of chromium steel, as presented by M. Osmond, we have the opportunity to make some deductions favourable to this steel. Its fine structure indicates shock-resisting qualities with high strength. From the same source we learn that, if over-heated, chromium steel is as worthless as any other steel.

The effects of annealing, as presented by Mr. Hadfield, are very pronounced. The ductility is raised, while strength and elasticity are left in good proportion. Taking all the known facts about chromium steel into consideration, we may safely conclude that it is a special steel, deserving consideration on account of its hardness, combined with forgeability, provided it is treated properly, and the method of production has secured a steel which contains not only the desired percentage of chromium uniformly distributed throughout every piece, but provided also that this desired percentage is present with allowable approximation to accuracy in every article manufactured.

If the above considerations of the qualities of steel appear rather ideal to some, the writer begs leave to say that, in the first place, we must have an ideal standard or basis to proceed from in determining our daily needs; in the second place, economic conditions drive the consumer more and more to obtain the ideal in everyday practice; while, on the other hand, daily experience proves that, with the advancement of knowledge of the nature of steel of all classes, and the perfection of the methods of production, this ideal has often been reached in the past, and will be more so in the future.

Mr. W. H. WHITE, C.B., (Director of Naval Construction): Having been unable to attend the meeting when Mr. Hadfield's paper was read and discussed, I should be glad to be permitted to express my sense of its great value to all interested in the manufacture or use of steel. It is a worthy successor to the series of papers by which the author has enriched the *Proceed-*

ings of the Institute. There can be no dispute that these researches into the properties of steel alloys have already had a great influence on practice, and promise to have a much greater influence in the future. My own experience with chrome-steel has been limited to its employment for defensive and offensive purposes. Most of the results I have seen with chrome-steel plates have been obtained with comparatively thin plates, fired at by guns of small calibre. These results have shown remarkable advantages as compared with ordinary qualities of mild steel. It is understood, also, that in deck-targets exposed to attack by oblique impact at small angles, chrome-steel has behaved well. For thicker armour plates, and normal impact, the corresponding advantages do not seem to have been so well established, and other modes of manufacture have been preferred.

It is most satisfactory to find British steel-makers so well maintaining their position in the manufacture of warlike material. That in some respects they have followed the lead of foreign manufacturers may be admitted freely, although it must not be forgotten that in many new departures they have taken the lead. In the manufacture of steel projectiles, the French undoubtedly showed the way. But the results to which Mr. Hadfield alludes with justifiable satisfaction show that, in this country, and by independent methods, projectiles in all respects equal to the best French projectiles have been produced. Recent developments in armour must necessitate a reconsideration of the descriptions and qualities of projectiles best suited to the new conditions. The problems thus arising may, one feels confident, be safely left in the hands of gentlemen who have already done so much valuable work in advancing steel manufacture.

Mr. J. E. STEAD had not had much experience with steels containing chromium, other than making chemical analysis of them. The little practical experience he had had on adding small quantities of chromium to open-hearth steel were not constantly satisfactory. Sometimes the effect of 0·1 per cent. had a decided toughening effect; at others, apparently none at all. He had concluded that chromium did not always have the same effect on the mechanical properties of steel, probably because it arranged itself

in groups or molecules with the iron differently under slightly differing treatment.

It had not yet been found out how to control the effect, and hence the use of chromium was for the time abandoned.

Personally, he thanked Mr. Hadfield for the almost exhaustive results placed before them, and recommended all the younger members of the Institute, and all who desired to study any metallurgical subject, to take as their model the original investigations of that gentleman, which were all types of method, order, and persistent and constant hard work.

Professor J. O. ARNOLD remarks: I have read Mr. Hadfield's masterly paper with much interest, and regard it as one of the most important contributions to the literature of practical steel metallurgy which has been written for many years.

I fully endorse the accuracy of his criticisms on my paper on chrome tyres, and accept his addition to my definitions of the influence of chromium on steel; but it will be noted, on reference to the original paper, that those definitions were applied only to *mild* steel. I am not at present in a position to deal with the important subject, only lightly touched upon by Mr. Hadfield, viz., the remarkable sensitiveness of chrome steel to the operations of hardening and tempering, and the diverse properties assumed by the same steel when treated under slightly differing thermal conditions.

With reference, however, to the table summarising the properties and compositions of unhardened steels, there are certain points open to criticism. In the first instance, it is to be regretted that in a research involving so much labour and thought, purer materials were not employed for the manufacture of the various ingots. Samples 1176 J to 1176 O contain silicon in such quantity as to render them not strictly comparable with the preceding steels, being, in fact, carbon-silicon-chrome steels.

There are two other points concerning which my experience of crucible chrome steels (extending over several years) differs greatly from that of Mr. Hadfield. Dealing with chrome steel up to 7 per cent., I have never had the slightest difficulty with the fusion of ferro-chrome (40 to 60 per cent.) My results, again, show it to be an element so little liable to oxidation

in the crucible, as to yield very certain results in obtaining the required percentage of metal. Mr. Hadfield, however, records losses ranging from 2 to 25 per cent. of the chromium added. It will be interesting, in the face of this discrepancy, to know the analytical method adopted for the determination of the chromium in the alloy and samples.

The following example (selected from the research series at the Sheffield Technical School) may be of interest, to compare with Mr. Hadfield's sample 1176 J, to which it is nearest in composition.* The ingot was melted from the following mixture:—

The ferro-chrome was added when the iron was "overhead," and the aluminium five minutes before teeming. The ingot "piped," but "topped" quite sound.

The 3-inch ingot was cogged to $1\frac{1}{2}$ inch square, and rolled to $1\frac{1}{2}$ inch round; it hammered and rolled excellently.

The mark N (normal) in the subjoined table has reference to the fact that the steel, after leaving the rolls, was raised to a bright red heat, and allowed to cool in air, in order to guard against any possible crystalline distortion in the rolls.

The sample marked A (annealed) was kept at a bright red heat for seventy hours, and packed in a box of sand placed on the bed of a reverberatory furnace. The furnace was luted up, and allowed to cool down during four days.

RESEARCH INGOT, 209.

Analysis per Cent.						Cr. added per cent.	Cr. Lost per ct. of total cr.	Original dimensions of test-pieces, inches.			Elastic Limit, Tons per square inch.	Breaking load in Tons per sq. in. on original area.	Elongation per cent.	Reduction of Area per cent.	Fracture.	Mark.
C.	S.	P.	Mn.	Cr.				Diam.	Area.	Length.						
99.0	13.6	0.02	0.02	0.06	5.23	5.31	1.5	0.562	0.248	2.02	49.64	61.85	10.00	19.87	Small crystals	N
								0.563	0.249	2.00	17.26	41.44	9.50	9.00	Small crystals	A

* The high silicon and manganese in 1176 J will probably considerably influence its physical properties.

	Lbs.	Oz.
⑤ Swedish bar iron	(Fe=99.8 per cent.)	44 0
Ferro-chrome	(Cr=44.3 per cent.)	6 0
Aluminium	(Al=99.4 per cent.)	0 0.5

It will be noted that only $1\frac{1}{2}$ per cent. of the total weight of chromium added was oxidised, and this is typical of a large number of results. This point is well worth clearing up, because Mr. Hadfield's experience would make it appear that the introduction of any desired percentage of chromium is a matter of some uncertainty. Mine points to an opposite conclusion.

One of the most satisfactory features of Mr. Hadfield's paper is his adoption of the correlative system I have so long and so vainly advocated for steel research. But whilst cordially welcoming the principle, I must strongly protest against the manner in which it has been carried out. The microscopical examinations and the recalescence observations have been made by M. Osmond.

Mr. Hadfield's mechanical test-pieces were from rolled bars $1\frac{1}{8}$ inch diameter. M. Osmond's micro-sections (presumably longitudinal) were from bars hammered to $\frac{1}{4}$ inch square, and, as he admits, distorted by the hammering. Such a comparison is valueless, and in no sense correlative.

Again, M. Osmond's alleged annealed sections are not annealed at all, but "normal," having been only heated to various degrees of redness and allowed to cool in air.

I have been engaged during the past five years in a close study of the micro-structure of steels, but must confess that to me much of M. Osmond's report is unintelligible. In the first place, he does not state whether his light was reflected from a parabolic or a 45° mirror.

His statement that the structure of a steel containing 0.16 per cent. C. and 0.29 per cent. Cr. is non-crystalline, and only visible under "high powers," is remarkable. My experience of such a metal is that it is highly crystalline, and the structure is distinct at 40 diameters.

His assertion "that the resistance to breaking of a mild steel represents the resistance between the grains, and not that of the grains themselves," is correct only to a limited extent. The interlocking of the crystals in mild rolled steel is so complete that a longitudinal micro-section at the point of rupture reveals the fact that so much resistance have the grains themselves opposed to the tension, that they have changed their forms from irregular cubes to long needles, usually termed fibres.

M. Osmond used for etching his sections water containing 20 per cent. by volume of nitric acid. I have found that water containing only 0.2 per cent. by volume of acid (or $\frac{1}{500}$ the volume employed by M. Osmond) is amply strong for chrome steels.

However, M. Osmond sums up his results as indicating—

1. That Sorby's pearly constituent of alternating laminæ is absent.

2. That chrome steels are practically devoid of crystalline structure.

The last statement is to some extent true under certain thermal conditions, but as a general principle it is inaccurate.

The first statement is not only inaccurate, but is the opposite of the actual fact.

My contentions are practically demonstrated by the following notes on the micro-structure of the normal and annealed bars of which the mechanical tests and analysis have already been tabulated herein.

The sections were transverse, and turned from the $1\frac{1}{2}$ inch bars on which the tests and recalescence observations were made. The micro-pieces were 0.5 inch diameter and $\frac{1}{16}$ inch thick. The polishing of each occupied about four hours. The etching acid consisted of 1 cc. of nitric acid specific gravity, 1.20, and 199 cc. of distilled water.

209 N.

The structure consisted entirely of ill-defined interfering crystals of the pearly constituent. The segregation of the component plates was imperfect, much diffused carbide being present. Here and there, however, fairly distinct crystals with well-marked laminæ were visible.

209 A.

The structure consisted altogether of large well-defined crystals of the pearly constituent, presenting even to the naked eye a beautiful mother-of-pearl appearance. Under the microscope, with oblique light, at 40 diameters the crystals gave splendid interference colours. At 630 diameters, with direct light, the laminæ presented all over the field a segregation and definition seldom found in carbon steels.

I may also state that in milder steels containing say 0.5 per cent. carbon, the addition of 0.5 per cent. chromium has a decisive influence in determining the more perfect formation of the pearly constituent.

RECALESCENCE.

Experiments made at the Sheffield Technical School fully bear out M. Osmond's statement that "chromium hastens the transformation of 'temper carbon' into 'annealing carbon' during the cooling of steel."

I have satisfactorily identified M. Osmond's critical point Ar_1 with the formation of Sorby's laminae, and yet M. Osmond states they are absent from chrome steels.

Taking as ordinates degrees Centigrade, and as abscissae minutes, the cooling curves of 209 N will be found to agree fairly well with M. Osmond's observations with reference to the influence of the rate of cooling; but, as regards the influence of initial temperature, they are very different, and present no appearance of self-hardening, even from a temperature 30° C. above M. Osmond's highest point.

This discrepancy may, however, be due to the influence of mass, and to the high manganese and silicon present in 1176 J when compared with 209, or possibly to an under-estimate of the chromium present. In my opinion the pieces employed by M. Osmond are far too small. Those used at the Sheffield Technical School are of a standard size, 6 inches long by $\frac{7}{8}$ inch diameter, recessed $\frac{3}{8}$ inch diameter by $2\frac{3}{4}$ inches long for the clay lead-tube, and $\frac{1}{8}$ inch diameter by $\frac{1}{2}$ inch long for the couple.

The results have been obtained on the lines laid down by M. Osmond and Professor Roberts-Austen, by means of that admirable instrument the Le Chatelier pyrometer. (To the published writings of these gentlemen I am much indebted for guidance in this matter, and again take an opportunity of expressing my conviction that their labours have given to steel metallurgists a means of observation which will in the future prove invaluable in all researches bearing upon the fundamental laws which govern the complex question of the physics of steel. At the same time I strongly deprecate the theories raised upon the present slender store of data.) My installation has a deflection of about 225

millimetres for 1000°C . The cold junction is kept at zero in alcohol jacketed with ice. The furnace is of special design, and can, if necessary, be taken up to steel-melting heat. So delicate is the whole arrangement, that it registers distinct *falls* of temperature at the carbon change-point on heating fairly hard steels. A large series of observations have already been plotted, and these, correlated with microscopic examinations, have yielded important evidence concerning the critical point Ar_2 . Some light has also been thrown upon the cause of the point Ar_3 . I hope to publish the section of the research touching these points during 1893, when I think M. Osmond and Professor Roberts-Austen will modify their views concerning the significance of these faint evolutions of heat.

MR. HADFIELD, in reply to the written discussion, desired to thank Mr. Paul Kreuzpointner, of Altoona, for his excellent contribution from the other side of the water. To call forth such a masterly explanation of the facts noticed in the testing of iron and steel productions as is offered by Mr. Kreuzpointner would be a reward and return to any author who had bestowed time and attention in the preparation of his paper, with a hope of eliciting information of value during the discussion which might follow.

The explanation suggested, that "where the matrix is harder in steel, there seems to be a more uniform stretching all over with the same ultimate strength, and total or even greater elongation," is probably the reason why manganese steel gives such enormous elongations—40 to 50 per cent., with 50 to 60 tons tenacity.

As pointed out by Mr. Kreuzpointner, the importance of obtaining steel free from foreign matter such as slag, which impedes continuity of structure (unlike the case of wrought iron, where the presence is tolerated, and probably to some extent necessary), cannot be too strongly impressed upon producers of a body with a crystalline structure such as steel, and than which there is no material more sensitive, or so subject to molecular changes. In Mr. Hadfield's opinion, the superior qualities of crucible steel have to some extent arisen out of their freedom from dissolved, or, if one may use the term, suspended matter.

The comparatively long-continued heating or refining of crucible steel, under conditions specially favouring the separation of such deleterious matter, permits of the production of an extremely pure product.

Mr. Kreuzpointner refers to chromium steel being used in the construction of the St. Louis and Illinois bridges. Mr. Hadfield had always understood that, though the statements were by some means circulated that such steel had been so used, they were incorrect, and that the material actually employed, when analysed, did not show even traces of the element in question. If chromium has been used for the above purpose, it would be very interesting to know what were the results obtained by the engineers in charge during construction. Did the tests show any marked superiority over carefully-made and well-selected carbon steel?

The methods adopted in the laboratory for determining exactly and precisely the percentages of chromium present in alloys do not seem as yet absolutely reliable. The author had obtained from different reliable sources most discrepant results. It was hoped, therefore, that metallurgical chemists will before long remove this blot from their practice. It was impossible to advance surely until our chemical eyes lead us aright.

Mr. Kreuzpointner's exceedingly practical remarks on the necessity of bringing practical observations to bear in selecting a suitable steel for a particular purpose, and not merely or entirely depending upon test results, deserves to be writ large in the notebooks of users of steel. As he rightly says, "Steel cannot be forced into the strait-jacket of a mathematical rule and formula."

Mr. Kreuzpointner's further remarks on this subject are fully borne out by the author, who has seen small armour-piercing projectiles with quite large pipes or porosities, discovered only after the firing test, successfully penetrate armour having a thickness nearly double the calibre of the shell, yet for other classes of work such steel might have been quite useless.

With reference to his concluding remarks, by all means let us have an ideal in steel-making, just as the painter has in view when working out his finest productions. Faraday, the idealist of so many forward movements, of which we are to-day reaping the benefits, and the master-mind of a past generation, did not deem the study of steel alloys beneath his notice, or beneath

his ideal mind. Nothing can be more interesting than the study and report that he made on his early experiments in this direction. Yes, as Mr. Kreuzpointner says, let us have an ideal standard or basis to proceed from in determining our daily needs.

Mr. Thwaite has been good enough to send an interesting communication, and it is hoped his remarks on the question of the adoption of the metric system will be taken to heart by members of this Institute. It was a great disappointment to find Sir William Harcourt, as Chancellor of the Exchequer, take recently, when meeting a deputation from the Decimal Association, so little interest in what is bound before long to prove a still more important trade factor in this country's communications with the world outside. The decimal system saves time, and there never was an era in which it would be more true to say that "Time is money" than the present.

Professor Arnold's remarks are of special importance, combining as they do the expression of opinion from one who is so fully competent to deal, both from its practical and its scientific side, with the considerations advanced for discussion in this paper. There may be some who feel hurt when met by directly opposite statements, advanced in good faith, but to the author it seems that sometimes a direct negative from either side of the controversy often ends in the "happy mean." It is hoped that this will be so in the points referred to by Professor Arnold, where differing from the report of M. Osmond.

Professor Arnold asks why purer materials or stock were not used as a basis for the melting operations. The author is of opinion that the influence of impurities, such as sulphur and phosphorus, within, say, .1 per cent. of the former and .06 per cent. of the latter, do not possess that influence in iron alloys, containing high percentages of a particular element, which is commonly supposed, or which might be expected from experience gained in the manufacture of ordinary carbon steel.

In the latter, when required of a high-class character, the question is a very different one. Without doubt, then, let the sulphur and phosphorus be as low as it is possible to get them, but in the present instance it is very questionable whether the results would be greatly different if the sulphur were reduced to half the amount actually resulting in the samples. The same remark applies to

the phosphorus, which, however, in the specimens under examination, is not high, but within ordinary limits.

Then, again, the author wished to use exactly the same stock as that taken for his previous experiments on silicon and aluminium steels, already described to the Institute. He thinks it would have been a mistake to make changes in this case, bearing in mind, too, the opinions expressed in the preceding paragraph.

As regards the difference of opinion between Professor Arnold and himself, as to the fusibility of the alloys, the author could only say that the high melting-point of rich ferro-chromium, as determined by M. Osmond, proves that there is something to be said for his view of the case. There is no doubt much in the particular method of carrying out the melting operations, and the author's experience may have been special in this case, as he willingly admits that in the ordinary production of chromium steel by his firm there is no very special difficulty, though considerable heat is required to melt the ferro-chromium alloys used.

Again, he has seen rich ferro-chromium come unmelted out of the crucibles used in the experiments detailed in the paper. M. Brustlein has also pointed out that chromium steel requires much special manipulation to ensure satisfactory results, both in the melting and in the teaming.

As regards the loss of chromium pointed out in column No. 9 of Table I., the author willingly admits that some special note might have been appended, stating that the loss given was known not to be entirely one resulting from oxidation.* The column in question (No. 9, Table I.) is, however, headed as being only approximate. In some instances part of the chromium was, as before named, not melted. This, no doubt, arose from the contents of the crucible not having been so carefully stirred as they should have been. Thus some of the ferro-chromium in small pieces remained in the somewhat viscid slag. This, in any case, would only concern one or two of the specimens, as most careful analyses have been made, both from the original ingots cast and the test bars themselves, and in each case where any discrepancy was noticed between the two the mean results were taken.

Professor Arnold, in an interesting conversation with the author on this subject, has called attention to the fact that in his

* This note has been appended to Table I.

(Professor Arnold's) opinion the Galbraith or volumetric method does not give strictly reliable results, and that he considers his own special method, which is the gravimetric one, more preferable. When doctors of chemistry disagree, who shall decide?

Mr. Stead has kindly determined the chromium in 1176 J for the author. The drillings were taken from exactly the same position as were those used for the determination at the Hecla Works. The following were the results:—

SAMPLE 1176 J.

Professor's Arnold's result	5.98 per cent. chromium.
Mr. Stead's result	5.54 " "
Hecla Works' result	5.19 " "

Another result at Hecla Works, taken from the same melting, but from a different part of the ingot, gave 5.44 per cent.

Probably 5.19 per cent. is too low, in view of the second determination at the Hecla Works, but of course, it is quite possible the ingot itself varied somewhat. At any rate, in face of Mr. Stead's determination, 5.98 would seem somewhat high. Trying to take an impartial view, one would be led to think Mr. Stead's result, being the mean, is more near the mark. It should, however, be stated that the latter's determination was, like that of the Hecla Works, done volumetrically.

Owing to the differences named, the author suggests that here is a good opportunity for an interesting paper to the Iron and Steel Institute. Claiming no pretensions as a chemist, he would suggest that, with such discrepancies, it would be well that the differing opinions should be thoroughly thrashed out on that happy hunting-ground of conflicting advocates—the well-known forum in Great George Street.

In concluding these remarks, it may be added that the author's firm has made many hundreds of tons of chromium steel in which accuracy of percentage was important, and the results of which have been checked very successfully by the volumetric method of estimation. Nevertheless, if the method is really unreliable, the sooner it is known the better for all concerned.

It may also be mentioned that Professor Arnold's research ingot "A," which does not materially differ from "1176 J" as

regards analysis, also gives mechanical test results varying but little from the latter.

It is with much sorrow (!) it is noticed, that the alloys described in this paper are spoken of by Professor Arnold and others as "chrome steels." The author has, after vainly struggling against the tendency of his own mind to adopt the perhaps more euphonic term "chrome steel," managed finally to eliminate numberless *e*'s in his and the printer's proof, arriving at, as it seems to him, the more correct designation of "chromium steel." To have his idol thus rudely destroyed, and from such quarters, is more than weak flesh and blood can bear. However, he humbly bows to the designation of "chrome steel," though in his own mind still clinging to the idea that "chromium steel" is really more correct. The former appellation is another proof of the wonderful law of evolution, and perhaps "a survival of the fittest." The element was originally known in France as "chrome," and the Britisher, with his liking for American condensation, quietly adopted this un-English designation.* Nevertheless, the author must make one last protest, as there is no such element as "chrome" known in our language, and we should never think of speaking of "silice" or "alumine" steel.

It is much to be regretted that M. Osmond, owing to urgency in closing the discussion in time for the publisher, has not an opportunity here of replying to Professor Arnold's criticism. The latter has been good enough to send on to Paris, for M. Osmond's inspection, his micro sections, and the author suggests that M. Osmond be asked to give a further paper in reply, as there is ample room for more light on this interesting question of the microscopical structure of chromium steel.

Mr. Stead has been good enough to give his experience. There is no doubt it is, as he says, very difficult to determine the exact influence of small quantities of chromium.

To Mr. W. H. White, C.B., Director of Naval Construction, the author is specially indebted for a vindication of the ballistic value of armour-piercing projectiles made in this country and under an English system. The author, in fairness to his own firm, must claim that they have successfully worked out this

* Yet to employ the word "bureau" has been recently considered by high parliamentary " " to be undignified and unpatriotic! "Where are we at?" is an American excellently sums up the anomalous situation.

difficult problem—at any rate as regards smaller sizes—when they accomplished the feat of supplying a projectile for the 6-inch R. L. gun, which twice passed uninjured through separate 9-inch compound plates, as well as from the numerous supplies accepted by the Government after passing the same reception tests at Shoeburyness as the foreign projectiles.

They have also improved the manufacture, so as to be able to supply them at less cost than those of French manufacture. It is, therefore, very satisfactory, amidst some difficulties and against some odds, to have a word of approbation from one with such wide experience of war material, as is the case with our able Director of Naval Construction. It has on several occasions been somewhat mortifying to an Englishman who desires to be able to supply any article required by his Government, to find that it has been thought necessary to order armour-piercing projectiles away from home. Mr. White's remarks are proof that there is now sufficient evidence before the Government to render this latter step needless.

With some little encouragement, such as foreign Governments seem to more readily bestow, English manufacturers can produce what is required—whether guns, armour-plates, or projectiles. It is, therefore, a special satisfaction to find this encouragement given from so high an authority, and in such a kindly manner.

As regards the thin shield plates referred to by Mr. White, it is quite possible that chromium steel may find a rival in manganese steel, some tests of which have given exceedingly good results. More are now in course of completion, and will soon be available, as a comparison.

In concluding his answer on the interesting written discussion, the author would venture to suggest that this method of carrying on discussion has many advantages. He ventures to think the several contributions will be found of considerable value to those interested in the progressive advance of the application of steel alloys. Many who would perhaps not otherwise contribute would by means of a written discussion come forward. The more widely papers can be discussed, the more can the objects contemplated by the authors be carried to a successful completion. He returns many thanks to these contributors, and for the assistance so cheerfully rendered by different helpers during the preparation of this paper.

FAILURES IN THE NECKS OF CHILLED IRON ROLLS.

BY CHARLES A. WINDER, M. INST. MECH. E.

DURING the last thirty years, great improvements have been effected in the machinery for rolling heavy iron and steel plates, which has reduced the cost of production, and enabled us to compete successfully with foreign makers, where the labour is less costly than ours. The ponderous gearing, which at one time occupied so much space, and was a source of great expense, has given way to direct driving. Three high rolls and hydraulic tables have been introduced; in fact, our modern rolling-mill is different in every way to that of the past, with the exception of the chilled iron rolls, which have to do all the work. These seem to have had very little attention generally, and the cause of any failure has been put down to inferior material, which in many cases may be true. Steel rolls have been adopted in place of grey iron for cogging, and also in large plate-mills, where finish and accuracy are not so important as safety, but, where a good face and accurate gauge is required, chilled iron stands firm against all attempts to displace it. It is not my intention, however, to enter here into the qualifications of the material, or its chemical properties, but as briefly as possible to consider a few details in connection with the design of rolls, and to set before you certain facts that have come under my notice during the last twenty years as a roll-maker.

Having had the privilege of inspecting many works on the Continent, as well as in England, Scotland, and Wales, and noting the different methods employed by various engineers and mill-owners in the manufacture of iron and steel, as well as the various proportions and designs of the chilled iron rolls employed in the manufacture of plates and sheets; having noted, also, the immense loss incurred in breakages, which may to a very large extent be prevented, it occurred to me that a few words upon the subject would not be out of place here, and might provoke a discussion which would be of benefit to the members of the Institute.

Many methods have been tried to improve the working qualities of the rolls, and there is still very much to be accomplished; but the only real improvement that has yet been successfully carried into effect is that of keeping the rolls cool by a copious supply of tepid water, without which it would be impossible to prevent disaster owing to the quick succession of hot blooms, which is nearly equal to the effect of a furnace. When we consider that the output for one pair of rolls was formerly only about 150 tons per week, and is now from 900 to 1000 tons, it is obvious that some provision must be made to accomplish the extra work. In many sheet-mills, indeed, there are no means whereby the temperature may be kept down in the body of the roll, which rises to that of oxidation; but, although the cooling of the body is not attempted, a good supply of water is often provided to keep the necks as cool as possible, so that the lubricant may not burn off, or the brasses cut. The consequence is, that an unequal expansion takes place in the body and the neck, and though the effect does not show itself at once, yet a weakening process has been set up which will eventually shorten the life of the roll, for a failure is certain, sooner or later, to take place if not provided against by a suitable design. By careful consideration the temperature of the roll may be gradually reduced, so that the atoms of the iron at the junction of the body and the neck of the roll are not subjected to a disturbing or disorganising influence.

Some years ago, my attention was drawn to certain difficulties in connection with the chilled rolls used in the tin-plate trade in South Wales, and what made the matter difficult to solve was the fact that, while most of our friends down there were well satisfied with the rolls in every way, some rolls were a source of trouble. Now the material of which the rolls were made was identical in each case, and the work they had to do was in all cases the same, but the results were extremely variable. Having a suspicion that the fault lay in the design, drawings were prepared of all rolls sent into that district, which showed that those which were satisfactory were different in design to those that failed during their work, and the appearance of the fracture in the broken roll clearly showed the temperature of the neck and the roll to have been quite different. The metal of the body had turned a dark blue colour, owing to oxidation, and the frac-

ture of the neck had remained perfectly bright, having, however, a ragged appearance, the metal in many cases hanging away from the face of the fracture as though torn away by great force.

Now it is worthy of note that all chilled rolls used in this branch of trade for hot rolling require to have an abnormally large diameter of neck; for instance, a roll having a diameter of 19 inches is never safe unless it has a neck of 14 inches diameter; but a similar roll for cold rolling is perfectly safe with a neck having a diameter of only 12 inches—in fact, a breakage has not at any time been reported to me; yet the pressure upon the bearings is considered to be equal in both cases, so that the only conclusion one can draw is, that the weakness has been caused in the hot roll by the unequal expansion of the body and the neck.

A very interesting visit was made to a tin-plate works some time ago, where the rolls were certainly designed with some degree of care and judgment, as shown in drawing No. 1, and, from inquiries made, the result was quite equal to expectations. On reference to the drawing, you will notice that the necks are much under the usual proportion for tin-plate hot rolls, and the diameter of the body is about the same; notwithstanding which, broken necks are almost unknown in this mill.

About the same time similar visits were made to other tin-plate works, where the rolls were made as shown in drawing No. 2, and much valuable property was found lying on the scrap heap. Now had these rolls all been made by some inexperienced ironfounder, it might not have been so significant, but an examination of the names upon the tennons showed that they had been manufactured by various makers who have the reputation for doing good work.

Other visits were made to ironworks in a different district, and the same results were shown, but in a much larger degree, as the rolls were some six or seven times the weight, and, as in the case of the tin-plate rolls, the fracture was precisely the same, as shown in drawing No. 3, and indicated by the red line *a b*.

Some time ago a report was given in one of the iron trade journals of a bankruptcy case, near Birmingham, when the bankrupt stated one of the causes of his failure to have been loss by broken rolls, and gave an estimate of £2600 for that

item. Being unaware of the nature of the breakages, and having had nothing to do with this particular house, I can only conclude that there must have been want of care somewhere.

An application was made to me some few years ago to supply a set of three grain rolls for cogging down billets for wire rods. It was pointed out by my friends that they had tried many roll-makers, but the result was always the same, and the neck at the leading gate end always came off after a certain period of work. It is not, therefore, surprising that a similar result happened in my own case. At the time, the actual cause appeared to be unaccountable, but the experience that has been gained since then convinces me that the failure was entirely due to the unequal expansion of the neck and body, for the leading gate was very close to the end of the roll (a mistake that is often made), thereby causing the end of the roll to be greatly heated near the junction of the neck, which was kept cool by means of a copious supply of cold water.

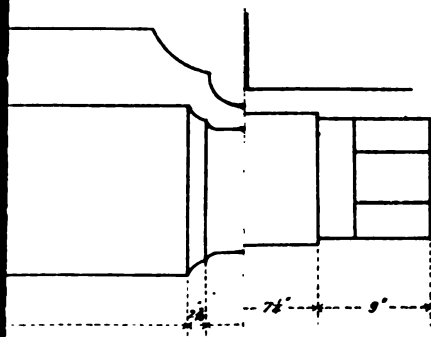
Another interesting case occurred about the same time, when the diameter of the necks of a pair of chilled rolls were reduced to save power, the area of the bearings was maintained, and the result up to a certain time was so satisfactory that the proprietor of the mill decided to adopt the smaller necks in the future, thinking he had given the rolls a fair trial after having run them about a month or five weeks. It was found, however, that we had been a little hasty in drawing our conclusions, and our plans were seriously interrupted by the necks breaking off. On examination, the fracture displayed a dark ring, which subsequent experience proved to be the result of an unequal expansion of the body and the neck, although at first it was put down to a faulty casting, having that appearance. Had it been so, however, a failure would have taken place much earlier. Evidently a rupture was set up on the periphery of the neck, and by frequent heating and cooling the molecular construction was disturbed, which caused the fracture to travel towards the centre, until the remaining portion became too small to resist the work put upon it. It is a source of regret that, owing to the death of the owner of the mill, the new design was never tried.

Continental mill-owners do not appear to suffer from the failure of roll necks so much as some of our mills at home, but

there are two good reasons to account for that fact. The first is, that they adopt a modified design, as shown in drawing No. 4—which is that of a roll belonging to a French house—and in drawing No. 5—which is working in Belgium; but the difference of design in No. 4 is not sufficient to account for the difference of result. It may be that we in England throw on our rolls much more work than they do on the Continent. This, indeed, is very probable. In the event of a breakage of a roll, the radii and diameter of the neck are often looked upon as the sole cause of mischief, and consequently they are in many cases increased to meet the required need. Trouble of this kind has been overcome by these means; but it appears to me that it is a very unscientific mode of procedure, and that bringing the neck up towards the diameter of the body is assisting to bring about another evil, and conducting the heat to a place where it is not wanted—the longitudinal cracks upon the face of the neck being evidence of over-heating: it also considerably increases the friction, particularly if the neck burns off the lubricant. Larger radii, without increasing the diameter of the neck, are not so serious, as it approaches the design of drawing No. 7, and reduces the diameter and temperature gradually, thereby allowing the neck to be kept cool without the fear of causing a movement of the molecules of the iron at the junction of the neck and body. This really is the duty performed by the large radii. Although it is by some used only as an extended area to give greater strength to resist the pressure upon the neck during the time the rolls are at work, yet it appears to be unnecessary, and productive only of evil. Of course, in estimating the breaking strains of the rolls as shown in drawing No. 6, we must take into consideration the torsional strain, and the resistance offered by the steel or other material that is being rolled as well; but as there are no data in my possession to work upon, probably the members present, many of whom are in daily contact with the work, may assist me. Very much of course depends upon the material, the temperature, and the draft; but it appears to me that the necessary pressure required to reduce steel at the heat at which it is usually worked is much below that of the breaking strains of the roll.

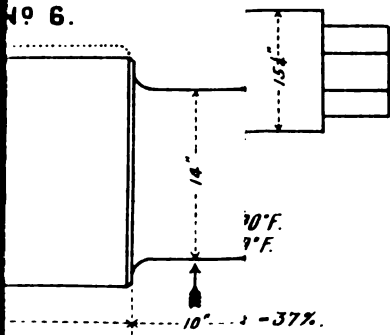
Drawing No. 9 gives the behaviour of the roll during work,

PLATE I.

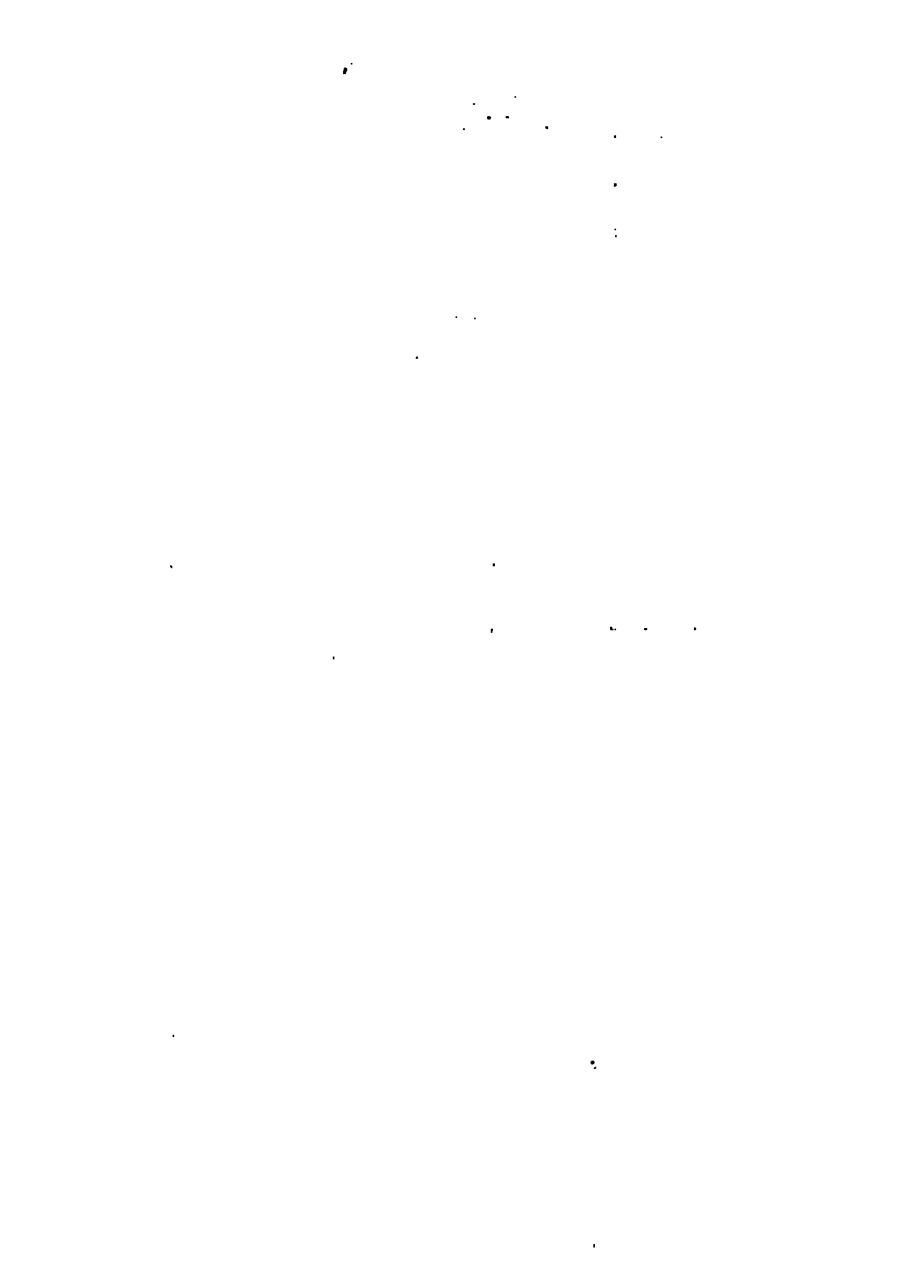


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and we may form some idea of the strain at the junction of the neck and the body by the difference of the temperature and dimensions at the different parts of the roll, which have been carefully noted by means of a micrometer. The tests were made immediately after the roll ceased work on a Saturday, and before commencing work on Monday morning.

Many more interesting cases might be brought forward, but they would only be a repetition of those already given, and are as well known to many gentlemen here as to myself.

Drawing No. 7 is a design for a chilled plate roll, which has been reduced at the end of the barrel, so that the temperature may not be so great at the junction of the neck and body, the roll having comparatively small radii; it has also a set-off at the end of the neck to which the tennon is attached, so that the strain in cooling in the sand is not so great as it otherwise would be when the two parts of the casting are so disproportionate.

Drawing No. 8 shows the same roll under conditions which are a fair sample of many others.

Before closing my paper, and in order to substantiate my views upon this question, let me ask you to consider that the failure of the necks of chilled plate rolls often takes place after a considerable period of working, though sometimes they occur soon after being put to work; but as the failures in those cases are attributable to some specific cause other than that which we have before us, we must leave them out of our consideration. Taking the larger number of rolls which have worked two, three, or more months, the fact that they have worked so long sufficiently proves that they are strong enough to resist the strains put upon them in the process of rolling, so long as the molecular construction of the metal at the junction of the neck and body is not disturbed; but at every heating and cooling, and also during the time they are at tension, as is the case in an unequal expansion, every vibration of the mill is assisting, though in a very slight degree, to cause a rupture which must eventually end in the failure of the roll neck and in serious loss to all concerned.

DISCUSSION.

The PRESIDENT, in inviting remarks on Mr. Winder's paper, said he thought that most of the members would agree with the conclusions contained in its last paragraph.

Mr. A. E. TUCKER said that having been connected for some years with the chemistry and use of chilled rolls, he would like to make some few remarks on the paper. It appeared to him that roll-makers and roll-users did not attach sufficient importance to the physical condition of the structure they were dealing with. He thought that a remark in the preceding paper, somewhat altered, might be applied to chilled rods. They might imagine a chilled roll to be a structure in which the molecules were in a state of intense strain, often relieved, in the case of a deep chill, by the material almost spontaneously rupturing itself. If they regarded a chilled roll in its true light, they would regard it as an almost glassy substance, surrounding a material more or less elastic, the actually chilled part of the roll being a material in a state of unstable equilibrium, which required a very slight cause to effect an incipient crack, the latter soon developing into a complete fracture.

We might also obtain some instruction from the remarks made on Mr. Hadfield's paper. Professor Roberts-Austen showed that the structure of iron produced at one temperature was probably different from that produced at another, so that we had a result of abstract science bearing closely on practical results—the point being that, from scientific deductions, independently of practical considerations, much attention should be paid to the heat at which a roll is cast. The physical characters of the metalloids contained in the material were very different when the metal was cast hot to what they were when it was cast cooler. It was within his experience that a roll had stood the enormous strain put upon it by the roller accidentally allowing a guide-plate, and in another case a tongs, to pass between the rolls when they were screwed

down, and not breaking the rolls, but being flattened to a thin section; whereas in rolling hot, and therefore soft, iron, in their ordinary use they broke. Such facts must point to a gradually increasing molecular or physical defect—probably developed or arising in the casting, and before leaving the maker's hands. If they bore in mind the treatment to which rolls were sometimes subjected before leaving the foundry, he thought they would have cause to attribute some failure to defective treatment in their early history. In ordinary everyday practice, rolls were taken out of the sand in a condition in which the interior must be more or less plastic—at all events, at a very elevated temperature. They were run out, perhaps into a yard, and exposed to the rain; they might be put either on to a very dry or a very wet surface, each condition being quite sufficient to establish a want of that physical uniformity which was, in his opinion, so essential to the good life of a chilled roll. Then again, follow the action of the runner at the bottom of the casting: if it be of large sectional area, it is smaller than the sectional area of the neck; it therefore cools sooner, and being attached to a mass of iron still in the process of setting or freezing, pulls at it and often cracks the thin skin of iron actually set; and thus we have another cause for rods so frequently breaking in the neck, and just in that place where, from mechanical considerations, they are, under ordinary conditions, least likely to break.

Mr. JEREMIAH HEAD said that, having in the past been a large user of chilled rolls, he was very glad to hear the subject introduced, because he was quite sure that a discussion upon it could not fail to be of utility. He could quite confirm what the author had said as to the terrible losses which occurred to the users of chilled rolls from frequent breakages, and also as to the fact that those breakages often occurred under circumstances which could not be explained at the time. The author had perhaps hit on one cause when he spoke of the desirability of not making too great a difference in diameter between the necks and the bodies of the rolls. Any experienced engineer would know that it was desirable that the gradations from the body of the roll up to the wobbler end should be as gradual as possible, that there should not be any sudden changes, and that the corners should be well

rounded off, so that there should not be any sharp nicks to tempt a breakage. Of course, the first thing which a user of chilled rolls specified and desired was that there should be a chill of something like five-eighths to three-fourths deep equally all round, and that the body of the roll should be free from pin-holes. That was the first thing which the maker should bear in mind; for unless those conditions were fulfilled, no matter what the enduring power of the roll might be, it was of no use. He had known a roll break in which nothing remarkable could be seen in the fractured section except a small pin-hole, which had been stopped up by a plug. This seemed to have been the starting-point of the breakage. It should also be remembered that the rolls were gradually turned down until, say, five-eighths deep of the chill was turned down to one-eighth, or until some part of it came to the soft iron. The condition of the roll when it was new, and when it was cast aside, were in that way considerably altered. If, when it was new, the molecules were in a state of equilibrium, or whatever the state of tension might be, it was clear that they might be materially different when the roll lost its chilled sheathing. With such changes in molecular balance, it was not to be wondered at if it stood very well at first and afterwards broke. In the casting of rolls the author had laid some stress on leaving a sufficient head at the top end of the mould. He believed that that was a very important point; also that, whatever the ultimate form of the roll, the casting should be made conical where one diameter merged into another, and that all sharp corners should be avoided, otherwise the scum or scoriæ would be apt to rest in the mould at the corners. There was no doubt that care in these respects was very necessary. He had noticed that, when rolls broke at the neck, it was always at the end corresponding with the top of the casting, and never at the bottom. The air spaces or blow-holes which were seen in ingots when they were cut in two vertically, were always found mainly at the top end. It was the same in chilled rolls, and that difficulty could only be overcome by casting on a sufficient head. He thought that they very often failed to get at the real cause of the breakage of rolls. The last speaker had hinted at tongs and other improper things being occasionally passed through the rolls. In his own experience, difficulties of that sort had

often occurred, and had been the cause of breakages. The men in charge naturally concealed any circumstances tending to inculpate themselves, and when a breakage happened during the night shift, it was usually nobody's fault. Whatever the real causes might be, he did not think they were yet fully understood. A paper on the subject was therefore very opportune, and any discussion on it was likely to be of great use.

Mr. CHARLES WOOD said it would be in the minds of a good many members that at the Spring Meeting a paper was read by Mr. Gruson on the subject of chilled casting, and some very good remarks were made on that subject, and also on the question of chilled rolls. Neither the author of the present paper, nor any one who had spoken upon it, had mentioned what quality of iron, and what amount of silicon or carbon, was most useful for putting into the rolls. In his opinion, the question of the quality of the iron put into the rolls had more to do with their breakage than almost anything else. If they had not the required quality, it was certain that the rolls would break as fast as they were put in.

Many years ago he had to cast a roll, not in this country, and he would not say where. It was cast direct from the blast furnace, and was exceedingly good iron. It was cast up on end, and with iron highly charged with carbon. It was only a small roll, but, when it was taken out of the mould, the whole of the top neck and all the git were found to be almost entirely graphitic carbon. The iron was almost minus, and the neck actually dropped off. That showed in a most remarkable way that it was very important to know in what position rolls were best cast, viz., whether horizontally or vertically, and what quality of iron was necessary to be put into them. It was quite certain that it should not be iron that ran direct from the blast furnace: it should be iron which was perfectly selected, of different qualities; and what they wanted to know was what those qualities were, and the analysis of them. He thought that if they had that they would very likely strike at one very important point as to the breakage of the rolls. At the same time it did not take much of a mechanic to understand that if the neck of a roll is not strong enough, they ought to make them

large enough to stand the strain, and this seemed to be the chief point of the author's paper.

MR. R. MARTIN (Swansea) said that he had had some experience of rolls breaking at the neck. He did not know the chemical analysis of the rolls, and he had never gone into the question of the mixture used in making them. Different qualities of rolls were made by different makers, but they had had trouble with rolls from the same maker, and of the same design. It might be interesting to the members to know that at one time his firm were plagued with a number of breakages of rolls *at the neck*, and they found the fault to be, not in the roll itself, but in the turning. If the roll were not accurately turned, or accurately rounded at the ends, it acted like an eccentric; and it was not surprising that, after a little work, the roll went. That was their experience. They had eleven rolls broken in a fortnight, and in their opinion it was due entirely to their not being accurately turned. That might help to explain one case that had been mentioned—of a works having tried the same kind of rolls, and having had no breakages. They might have had a good roll-turner, and he might have always turned the rolls exactly round. On the other hand, the roll-turner might have a substitute who did not know how to turn the rolls round, and there might be breakages arising from that cause which perhaps had been sought for elsewhere.

MR. GEORGE BEARD said that he had probably had more experience in the use of sheet-iron rolls than any member present. He could only speak as to his own practical experience. About forty-five years ago, he was standing by some rolls, where his father was rolling, at the Gospel Oak Ironworks in South Staffordshire. As nearly as he could remember, they were using at that time rolls 18 inches in diameter, with necks of about 12 inches diameter. His father was finishing off some very light sheets with practically no pressure whatever on the roll, and as the sheets rolled out at his feet, the outside neck of the bottom roll bowed out noiselessly, the fracture being conical in shape. There was nothing in the fracture to show why it should bowl out in that way. Occasionally, but only occasionally, during a long practice, he

had seen the same result without anything to indicate the cause of it. There was, in the case he had mentioned, more shoulder in the neck than in one of the drawings shown by Mr. Winder, in which the angle of the shoulder was very acute; and he should not be surprised, therefore, at a neck of that description breaking off at any moment.

Reference had been made by the last speaker to rolls being out of the round. In his experience that did not arise from the fact that the bodies were out of the round, but from the fact that the wobbles at the end of the neck were not centred properly. The roll-turner, in order to divide equally the chill upon the surface of the roll, centred his wobbles to suit the chill; and in doing that they found, when the rolls were finished, that the wobbles were not centred with the body of the roll. Hence it acted like a cam, the rolls being carried up and down, especially when the boxes got tight, and worn or locked, oftentimes carrying the neck and breaking it off. In drawing No. 3 there was a fracture from the neck across into the body. In the whole of his experience, he had not seen a fracture of that kind take place, except in a roll cast with hard metal, and with a deep chill. It had never occurred in his experience when the chill had been from $\frac{3}{8}$ to $\frac{1}{2}$ inch deep. He therefore attributed the fracture to the fact that the metal was too hard, and the roll consequently chilled too deep.

Too much importance could not be attached to the remarks made by Professor Roberts-Austen, who had given some drawings upon the board. It was well for the trade that chemists had thought it wise to come to their assistance. He was quite sure that there was a great field for research in the direction of the strength of metals at various heats. When that was thoroughly understood, he thought many of their difficulties would be easy to understand. He remembered that many years ago, at the Weardale Iron Company's works in Durham, there was a very extraordinary mill in operation. The rolls were 3 feet in diameter and 6 feet long, with necks only 17 inches diameter. There was a core cast through the centre of the rolls, 12 inches diameter, reduced to $4\frac{1}{2}$ inches diameter through the neck and the wobbles. The necks, although exceptionally small for the diameter of roll, stood the work remarkably well. The

operation of the roll was very different from anything in use at the present time. Instead of the iron being passed backwards and forwards through the rolls, or taken over and under, it was thrown, by means of travelling tables, from one pair to the other (two pairs of rolls of the same size being used), and it kept going round the circle from roll to roll until the operation of rolling the plate was complete. The process was a very difficult one, and it was ultimately abandoned; but it led to an alteration of the mill, and the adoption of 26-inch plate-rolls, with necks 17 inches diameter—the same diameter as previously used for the 36-inch diameter rolls, with a core cast through the rolls, similar to the rolls which were adopted in the larger roll. He found this extraordinary feature in the working of the rolls—for he was rolling at the time—that in raising the temperature or heat of the rolls, if the temperature was raised too fast, instead of the rolls breaking off at the neck or through the body, large pieces of the chill would fly out to the depth of the chill. In every case where they had a breakage from rolls cast in that particular manner, the breakage under a forced temperature was of the manner described. That, again, showed that there was a necessity for understanding the radiations of heat, which appeared to be very imperfectly understood at the present time. The depths of the chill was a very important feature with regard to the life of rolls. In practice he had not found chills of $\frac{3}{4}$ inch deep reliable. As a general rule, it was very rarely that they would work, under ordinary working rules, more than a month at a time: sometimes they would go on longer, but ultimately the break came.

He remembered another very extraordinary case, with regard to rolls, in South Staffordshire. It was the breaking of some twelve or fourteen rolls in succession, all through the middle, after working from about three to fourteen days each. The chills were shallow, and of the ordinary workable depth. There was nothing in the fracture of the rolls to indicate any special cause for the breakage. The real cause of the breakage of those rolls was a mystery at the time. Members might know that there were two classes of pig iron made in the South. At the same furnaces from which they obtained the best selected iron for rolls there was also what was known as strong

forge iron, similar in fracture. The difference between those two, of course, was better understood by experts in the manufacture of pig iron than by himself; but he found that the whole of those rolls which broke in that way had been made from strong forge iron, and not from the best selected. Hence the presence of a large percentage of sulphur, which was no doubt the direct cause of the breakage of those rolls. He hoped the few experiences to which he had referred would be some inducement for a continuation of the discussion, because he was quite sure, having regard to the number of rolls that were annually broken, there was a wide field for scientific research. At the same time, as was mentioned by Sir James Kitson on the previous evening, not only the plate-rollers, but sheet-rollers and tin-plate rollers, were practically working, in these times of profitless trading, for the benefit of the public, and not in their own interest; and it would be a very great boon to the trade if something could be done that would reduce the cost of those very expensive articles, which were daily used, and which were essential to the carrying on of their manufactures.

MR. WILLIAM MOLINEAUX said that he had been waiting to hear something new in regard to the breaking of chilled rolls, but so far he had heard nothing of the kind. After an experience of more than fifty years in turning, and in using chilled rolls, he found that they were practically where they were fifty years ago. He well recollected at Bishop Wearmouth Ironworks they often could not get the chilled rolls to stand for a week together. They sometimes broke in two or three days, and for some three months rolls could not be got that would do the work of rolling thin sheets. A foundry of very high reputation supplied these rolls, and during the last three years he had had rolls from the same foundry, and had found the same thing. He was surprised to find that the author of the paper had confined himself to the necks of chilled rolls. It might be that in plate-rolls that was often the case, but, according to his experience, where one neck was broken off, there were certainly a dozen or twenty that broke through the body. He thought that the quality of the iron had as much to do with it as the fault of the users, who were still, however, much in ignorance of the subject.

After fifty years' experience, there was a great deal to be learned, and it would be well that both makers and users should give the matter their special attention.

In England, as in America, they were still at fault with respect to the making and using of chilled rolls. Theories had been set up as to the unevenness of turning, as to the depth of the chill, and as to the rolls being cast hollow. They were cast hollow fifty years ago. Four or five years ago a gentleman had come to him and said that he had paid special attention to the matter, and that being confident he had got the right idea, had taken out provisional protection. It was to cast the roll with a hole two inches in diameter through the centre, and then to run warm water through it. He told the gentleman that the rolls were cast hollow fifty years ago, and the only addition was in running the warm water through them. He said, however, that he was willing to try a roll made in that way, and he did so, and it broke in three days. He thought that the matter was one which should receive the best attention of the Institute.

Mr. T. TURNER (Birmingham) said that Mr. Wood and other speakers had referred to the circumstance that a little more information was required with regard to the suitable composition of cast iron for the manufacture of rolls.

Several papers had been read before the Institute in Germany and elsewhere on the subject, but, as far as he had noticed, they did not give the information most desired. The composition of cast iron for roll-making was generally regarded as somewhat of a secret, but he did not think he should be giving anything away in telling the members what they could find out for themselves by simple analysis.

With regard to the quantity of carbon in iron for making chilled rolls, it was generally considered that the proportion of carbon should be as high as possible, because, with a high percentage of carbon, they generally had a very good quality of cast iron—one that had possibly been made by the cold blast, or at all events by a slow-working furnace which gave a good quality of iron for the purpose. The most important constituents to be considered, however, were the combined carbon, sulphur, and

The proportion of silicon in good rolls was usually

about 0.85 per cent., varying somewhat according to the size of the roll and the depth of the chill required. The amount of sulphur in a good roll was about 0.07 per cent. It should never exceed 0.15 per cent., or the combined carbon would be too high, and then the roll became brittle, and fracture resulted. The amount of combined carbon taken in the unchilled part of the roll should not exceed, or only very slightly exceed, 1 per cent. About 0.6 was a good percentage of combined carbon. With regard to phosphorus, there was a little difference of opinion among makers. Personally, he liked a little phosphorus, because he believed it gave strength to the iron; but if there was much phosphorus where the roll had to stand a considerable amount of shock, it broke across the barrel part. The amount of phosphorus should not be more than 0.6 per cent. at the outside. Many makers preferred about one-third of that quantity. With no phosphorus, the results were certainly not so good. The amount of manganese present could be varied to some extent without injury to the product. Upon that subject he had not so much definite information; but within a few tenths per cent. it made comparatively little difference. Anything above one per cent. of manganese was bad for iron that required considerable strength. Of course, these figures would vary somewhat, one element varying a little as the other elements varied, and the whole varying according to the depth of chill and size of the roll. That was a general indication, and possibly some other speakers would give their experience, for he knew there were gentlemen present who had had considerable experience as to the composition of chilled rolls, if they only cared to speak out.

MR. CHARLES WINDER, in reply, said he had anticipated that the chemical question would be brought forward, and although it was a distinct investigation, he had taken it into consideration. He had been engaged in it nearly twenty years, he had spent a considerable amount of time and money over it, and all failures had been carefully investigated analytically. The facts which had been taken into consideration had reference to the same quality of iron. He had carefully avoided discussing anything in connection with the varieties of iron employed in the manufacture of chilled rolls, because it was too large a subject

to be treated in his paper, his object being only to give parallel results in rolls made of the same quality of iron.

A remark had been made with regard to No. 10 roll, which roll was working in a Staffordshire mill at the present time, in the same house as No. 1, only No. 1 was used for hot rolling, and the other for cold rolling. He had already remarked that at this place they hardly knew what broken roll necks were, comparing it with some others, which had very large radii and no reduction at the ends of the body, that were constantly failing. He thought that the whole question was summed up in this—if a hot roll had a blunt end, or, in other words, was not reduced at all towards the neck, and the neck was out of proportion with the body, the result was bound to be a failure. On the other hand, with a cold roll it did not matter so much, owing to the simple fact that there was comparatively no difference in the expansion between the neck and the barrel. That was really the one point that he wanted to bring forward. He thought that it had been conclusively proved that the failure was caused by a greater expansion of the body than of the neck, and by a simple reduction at the end of the body it could be overcome. The only objection was that the standards would have to be set a little farther apart.

Reference had been made by one gentleman to the matter of necks breaking by bad mounting. He concluded from the speaker's remarks that such necks were evidently fixed in standards which were not secure. He had often noticed this, so that when each plate went through the rolls, the standards jumped fairly out of plumb. They could not expect the necks to stand under such circumstances. Probably they were castings which had never been machined at all. Those cases must be left out of present consideration.

The fault in many cases, as he had remarked in the paper, was caused by carelessness, but when they had such direct evidence as there was before them with regard to the design, he could only come to one conclusion.

Mr. CHARLES WOOD said the author had remarked that he obtained his iron from *one* place, and always one quality. Iron was always selected at furnaces by fracture, and not by analysis :

at some years ago he read a paper in which he proved clearly that there was constantly a great variation in the iron, showing the same fracture even when made from the same furnaces with the same treatment. This variation, due to the difference between the silicon and the combined carbon, was quite sufficient to make the iron very rotten or very tough, as the case may be. Therefore, if the rolls were made, as the author stated, from iron made at one place and always of the same quality, it quite accounted for some rolls standing so much better than others.

Mr. WINDER said that Mr. Wood had misunderstood him in regard to getting iron from the same furnace. He used several brands in the mixture, which were constantly being changed, as the quality varied, and every brand was subjected to careful analysis. He kept a chemist at his works doing nothing else, every brand being analysed; and all scrap which was used after being run down through the furnace into pig was also subjected to the same investigation before it was used in the roll. In the present instance, he had made careful analyses, and had paid attention to all other points which were liable to lead him astray.

The PRESIDENT said he thought Mr. Winder should be congratulated upon having produced a valuable paper, which had raised a useful discussion.

THE UNIVERSITY COLLEGE WALKER ENGINEERING LABORATORIES AND THE SCHEME OF ENGINEERING INSTRUCTION.

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THE following brief paper, which has been prepared in response to a communication from the secretary of your Institution, is divided into the two parts indicated by the above title—the former being a description of the building and equipment which will be inspected by members to-morrow morning, and the latter a detailed account of the nature of the technical instruction in engineering, which forms one branch of work in the University College of Liverpool.

(1.) THE WALKER ENGINEERING LABORATORIES.

The above building, which was erected and equipped at the expense of a Liverpool citizen, Sir Andrew B. Walker, Bart., was opened three years ago to take the place of the temporary premises which had been used during the preceding four years of the establishment of engineering teaching in the college. From the general view shown in the first diagram, the laboratories are seen to consist of a building of three storeys, to which is attached another building of one storey, the latter being the wood-working department, the structure, in common with all new college buildings, being of grey brick and red terra cotta. The frontage (which is on Brownlow Hill) is continuous with that of the new Victoria buildings of the college, the whole extending a distance of 400 feet. The latter building, quite recently erected for the better accommodation of the art portion of the college, consists—in addition to numerous class and lecture rooms, professors' and students' rooms, offices, &c.—of a large lecture theatre to seat 700 persons, the Tait Library, and the

Jubilee Clock Tower, the inaugural ceremony taking place a few weeks hence.

The Walker engineering laboratories are entered from the road through a fine arch of Norman character, in terra cotta work, which serves to join the laboratories to the new Victoria building. The visitor enters the vestibule (A), shown upon diagram No. 2, which is a plan of the ground floor of the building, at the foot of a few steps leading to the main entrance of the hall (B), the vestibule being separated from it by means of a screen of folding doors. Granite columns support arches through which the visitor passes into the hall, which is spacious, the walls having a dado of salience work with mosaic floor, and in which stands a full length marble statue of H.R.H. the late Duke of Albany, by Count Gleichen.

To the right is a balcony (C) looking over the main laboratory, and arranged so that visitors can see the work going on without entering the department. To the right of the passage in front is the door (D) leading to the resident caretaker's rooms, and on the left is the cloak-room (E) and dressing-room of the students, which is sufficiently lofty for an iron gallery running round it, on which are lockers for overalls and workshop aprons. Descending a few steps, there is immediately in front the wood-working department (F), which can be shut off from the main building by a fireproof door; while to the right there is a side-door (G), through which the main laboratory and workshop can be entered. This department, which can also be entered from the vestibule by a door (H), is 70 feet long by 60 feet wide and 22 feet high, and is lined with ivory-white glazed brick with sienna dado.

From the plan of the arrangement shown in the diagram, it will be seen that the laboratory (K), containing the various testing machines and experimental apparatus, is now partitioned off from workshop (L) by a screen. The former contains a 100-ton Buckton single-lever testing machine with alternative centres, described last year in a paper by the author before the Institution of Mechanical Engineers,* which has proved to be at once extremely convenient and satisfactory, both for the instruction of students and for commercial testing. In addition to the large

* *Proceedings of the Institution of Mechanical Engineers*, August 1891.

machine, there are various smaller testing machines, for cement and other materials, and other pieces of experimental apparatus. The diagram shows the general arrangement of the workshop, which is well equipped with the usual workshop tools and appliances, and has, in addition, a Westinghouse air-compressor, a Worthington pump, and other machines for experimental purposes.

The power for driving the tools and working the testing machine is derived from a 40-h.p. Robey vertical engine. Here will be seen at work the new American chain-making machine, which has been sent over from America specially for this meeting, a complete description of which might have formed the subject of a separate paper before the Institute. As the list of papers was, however, already made up for the meeting before the idea of doing this occurred to the author, he has prepared a description of the process, which, together with a copy of a paper read at the recent meeting of the British Association on the comparative tests of the new form of chain made by the machine, are available for distribution amongst the members who intend to visit the laboratories to-morrow. The experimental engine, of 150 i.h.p., of the triple expansion marine type (also, with its boiler, fully described and illustrated in the paper previously alluded to), stands near the Robey engine, and is fitted with every appliance for the instruction of students. Passing out of the main workshop by a door near the experimental engine, the boiler-house is reached, where is the experimental boiler of marine type, the workshop boiler of locomotive type, and a forge anvil, moulding bench, small melting furnace, and other appliances.

The wood-working department contains thirteen benches, with accommodation for twenty-five students, and there are ten lathes, besides machines for preparing work, such as a circular saw, band saw, hand-planing machine, &c., the machinery being actuated by an 8 h.p. Fawcett gas-engine.

Passing out of the wood-working department and across the hall, the staircase leads to the first floor (see Diagram 3), reaching first the museum, the original emptiness of which is already being changed, thanks to the kindness of several engineers and of former students, whose occasional gifts of models and specimens are of the utmost value and importance. It may not be out of place to remark that it is not only models that are of intrinsic

value, and often very costly, which are acceptable, but examples of corrosion or fracture, or of the effects of wear and friction, and specimens of new engineering or building material. In the museum are arranged several models which have been kindly lent by the owners for the occasion of the visit of your Institution, and are referred to on a separate printed slip.

The lecture hall, which may be entered from the museum, contains 128 separate desks, with teak tops, for students, though as large an audience as 250 has been accommodated on rare occasions. The lecture table is very completely fitted up, not only with the ordinary gas and water appliances, but with hydraulic attachments to the experimental water tank in the Jubilee Clock Tower, fittings to the air compressor, and electric attachments to the dynamo, and has a small glass tank for exhibiting the effects of buoyancy, stability, &c. There are also complete lantern and blackboard arrangements. The lighting, warming, and acoustic properties have all proved very satisfactory, and the room is a most pleasant one, at any rate for the professor, a feeling which he charitably hopes is shared by the students, though he does commit himself to the latter as an expression of opinion.

Adjoining the lecture hall is the apparatus room, where lecture models and appliances are kept, and next to this is what was originally intended to be a class-room, but which has recently been fitted up with benches, lathes, and a milling machine, as an experimental workshop, by means of a donation of £200 kindly given by E. K. Muspratt, Esq., Vice-Chairman of the College Council. Adjoining this is the professor's private room, connected with which is the office, which forms a convenient ante-room. At the end of the passage is a circular iron staircase, which gives a ready and convenient means of access to and from the main laboratory.

Passing down the passage (which goes under the raised slope of the end tiers of seats in the lecture hall), the museum is again reached, and thence, by the stairs, the Mezzanine floor, from which the upper tier of seats in the lecture hall is attained, from the landing of which latter, the museum can be overlooked from a balcony. On the Mezzanine floor, and over the office and passage, is the diagram room, where wall lecture diagrams are prepared and stored.

Ascending still further, the top floor is reached (see Diagram 4), and the passage to the right leads to the drawing hall, which occupies the whole width of the building. This hall is well lighted from the north, east, and west, while at night arrangements have been made for both gas and electricity. There are between forty and fifty drawing tables, each of which has a separate electric light. Adjoining the drawing hall is the lecturer's room, and beyond the private room of the other engineering assistant, the other rooms on the floor being classrooms.

Above this floor is constructed a photographic room and a dark room, which form an institution of the greatest importance, not only for copying engineering drawings, for which the space on the roof is requisitioned, but for preparing lecture lantern slides, which save a vast amount of the time previously expended in the preparation of lecture diagrams.

The foregoing description does not attempt to deal with the architectural and constructive features, of which the members will obtain a better idea by actual inspection; but it may be mentioned that the position of the laboratories, directly over the main line of the London and North-Western Railway Company between Lime Street and Edge Hill, and the peculiar nature of the ground, involved great difficulty and expense in the matter of foundations, and on this account there are a sufficient number of girders buried there to give the building an interest in the eyes of the Iron and Steel Institute, from what might be called a cemetery point of view.

(2.) THE SCHEME OF ENGINEERING INSTRUCTION.

The author has less hesitation in dealing with this portion of the subject than he would have were it not for the expression of opinion by various practical engineers in the discussion of a paper read by him before the Liverpool Engineering Society a year ago. This paper, entitled "The Education of an Engineer," was somewhat general in its nature, and it was clear that further details concerning the precise nature of the subjects of instruction in a modern school of engineering would have been welcome, which was, of course, a thing so contrary to his usual experience,

at any rate in dealing with the engineers of the future, as never to have occurred to him. It seems, however, to be felt by many that enough, and perhaps too much, has been said during recent years concerning technical education generally; and it may be a valuable thing to take advantage of an occasion such as the present, to elicit the opinion of practical men upon the actual details of a scheme of instruction in one of the numerous colleges which include a department of engineering as a branch of their work. It may be at once remarked that a good deal of what follows may be gleaned by an industrious perusal of the separate engineering prospectus of the college; but, without any imputation on the range of reading by members of the Institute, it may be inferred that few of them have ever seen or heard of that publication.

The object then of the department is to provide instruction for those intending to become engineers, or to enter any of the allied professions, and to supplement the ordinary training by systematic technical teaching. Such training, it is clearly stated, "must only be regarded as preliminary to, or supplementary of, a pupilage under some engineer, or course of apprenticeship with some engineering firm." In short, it is the object of the college to work in co-operation with both the engineer or engineering firm who receive students after their college training, and the schoolmaster. Complete courses of instruction (including mathematics, physics, and chemistry) are provided in

- (1) Civil engineering.
- (2) Mechanical engineering.
- (3) Electrical engineering.

In view of the above quotation, it will be understood that during the first year or two the three courses differ very little from each other, and the object in view is to secure a sound training rather than an extensive acquaintance with the facts of engineering. The importance of this in dealing with lads of sixteen or seventeen years of age, of which an increasing number come every year to the college, cannot be over-estimated, especially as many are destined to become shipowners and manufacturers. The annexed time table for the first year stands, in fact, for all three above courses, with the simple addition of a course on surveying for the civil engineering students during the summer months.

CIVIL, MECHANICAL, AND ELECTRICAL ENGINEERING.

FIRST YEAR.

	9.0	9.30	10.30	11.30	12.30	1.0	1.30	2.0	3.0	4.0	5.0
<i>Monday</i> ..		Inter- mediate Ma- thematics.	Engineer- ing.	Junior Mathe- matics.	Pract. Physics (1) P.	Engineering Design.				Physic	
<i>Tuesday</i> ..		Workshop.		Mechanics. Physics.				Drawing.			
<i>Wednesday</i>		Inter- mediate Ma- thematics.	Engineer- ing.	Junior Mathe- matics.	Pract. Physics (2) P.	Descriptive Geometry.				Workshop.	
<i>Thursday</i> ,		Workshop.		Mechanics. Physics.				Descriptive Geometry.			
<i>Friday</i> ..		Inter- mediate Ma- thematics.	Engineer- ing.	Junior Mathe- matics.	Pract. Physics (3) P.				Workshop.		
<i>Saturday</i> ..		Problem Class.	Mechanics.	Workshop.							

Practical Physics (1) P, (2) P, and (3) P are alternative.

With regard to civil engineering, the course is intended to meet the generally acknowledged want of a preparatory training for one or two years before the usual entry as articled pupil into an office. Pupils are frequently articled to a civil engineer for the comparatively short term of three years, and this scheme possesses the advantage of utilising the interval between leaving school and entering an office. The co-operation of civil engineers in the neighbourhood is invited, and almost invariably is heartily accorded, so that the time spent at the college is recognised by them in receiving pupils. Such pupils, after passing through a satisfactory course at the college, are received on more favourable terms than otherwise. When a longer term of pupilage than three years is entered upon, a clause is often allowed by them in the articles enabling the pupil to attend advanced or special day lectures at the college during the first or second years of pupilage.

The course of civil engineering extends over two years, the details of the lectures and classes for the second year being given in the time-tables (p. 9). Special arrangements are made for students who remain for a third year.

With regard to mechanical engineering, although each year's course is arranged to extend over the whole academic year, yet the scheme is specially prepared so as to enable students to enter engineering workshops in the neighbourhood during the

six summer months. This system has now had several years' trial, both in Liverpool and at one or two other colleges, and the results have proved in general highly satisfactory. The number of engineers ready to accept pupils on these terms is increasing, and the greater proportion of students in mechanical engineering take advantage of the arrangement, coming back as a rule for the following winter session much more satisfactory material from the professorial point of view. Students who have passed through a three years' course in this way are eligible to compete for the Whitworth scholarships and exhibitions, and though any mention of the college scholarships would be out of place here, the knowledge concerning the details of this magnificent endowment is not so widespread as to make the following facts superfluous.

There are each year four scholarships of £125 per annum, tenable for three years; ten £100 exhibitions, and twenty £50 exhibitions, tenable for one year. They are open for competition to all Her Majesty's subjects under the following conditions:—The candidate must be under twenty-six years of age on the 1st of May; he must have been engaged in the workshop of a mechanical engineer for at least three years, and have been at work at the vice and lathe, or the forge, or the bench, for at least six consecutive months in each of those years. He must have spent at least twelve months at the vice and lathe, not less than three months having been spent at the vice, and three at the lathe.

The competition will be in the following subjects of the Science and Art Department Examinations:—

Practical geometry.
Machine drawing.
Building construction.
Naval architecture.
Mathematics.
Theoretical mechanics.
Applied mechanics.

Sound, light, and heat.
Magnetism and electricity.
Inorganic chemistry.
Metallurgy.
Steam.
Freehand drawing.

The candidate may select as few or as many of the above subjects as he pleases, except that machine drawing, building construction, and naval architecture, are alternative, and that no candidate can obtain a scholarship who has not passed in the advanced stage, or "honours," of practical geometry, and in the second or third stage, or the "honours" of those stages of mathematics; and he must have obtained a first class in the

elementary stage, or passed in the advanced stage, or "honours" of theoretical mechanics, and he must have passed in the second grade of freehand drawing.

No candidate can obtain a scholarship who has not attained sufficient handicraft power. If thought necessary by the Department, this may be tested by requiring him to make two Whitworth screw bolts, 1 inch in diameter, and 4 inches to 6 inches long, with hexagonal heads and nuts, alike within .001 inch.

Further particulars are to be found in the Whitworth prospectus, price 3d., to be obtained from the Secretary, Science and Art Department, South Kensington, S.W.

The time table of the civil and mechanical engineering course for the second year is practically the same, and is as follows:—

CIVIL AND MECHANICAL ENGINEERING.

SECOND YEAR.

	9.30	10.30	11.30	12.30	1.0	1.30	2.0	3.0	4.0	5.0	
Monday ..	Pure Mathematics.	Laboratory (Main Workshop).			Surveying.			Geometry.	Chemistry.	Machine Design.	
Tuesday ..	Applied Mathematics.	Engineering.	Experimental Workshop.					Drawing and Design.		Physics.	
Wednesday	Pure Mathematics.	Laboratory.	(Testing)	Physics.				Physical Laboratory.	Chemistry.	Physical Lab.	
Thursday .	Applied Mathematics.	Engineering.	Main Workshop.						Descriptive Geometry. Surveying.		Physics.
Friday ..	Pure Mathematics.	Laboratory.	Patternmaking.						Physical Laboratory.	Chemistry.	Physical Lab.
Saturday .	Applied Mathematics.	Engineering.									

The scheme of electrical engineering is worked conjointly with the physical department, and the time table approved by the Senate, as given below, will be found to correspond closely with the courses in civil and mechanical engineering, special instruction being provided in the subject of electro-technics. It is stated in the prospectus that "in this, as in other branches of engineering, college teaching can only supplement, but must not displace, the training upon actual engineering works.

ELECTRICAL ENGINEERING.

SECOND YEAR.

	1.30	10.30	11.30	12.30	1.0	1.30	2.0	3.0	4.0	5.0
Monday	Pure Mathematics.		Engineering Laboratory. (Metal Work.)					Geometry.	Chemistry.	Machine Design.
Tuesday	Applied Mathematics.	Engineering.	Electro-technical Laboratory.					Drawing and Design.		Physics.
Wednesday	Pure Mathematics.	Engineering Laboratory. (Testing.)		Physics.				Physical Laboratory.	Chemistry.	Physical Lab.
Thursday	Applied Mathematics.	Engineering.	Electro-technical Laboratory.					Descriptive Geometry.		Physics.
Friday	Pure Mathematics.	Engineering Laboratory. (Patternmaking.)						Physical Laboratory.	Chemistry.	Physical Lab.
Saturday	Applied Mathematics.	Engineering.	Electro-technical.							

The third year's course of instruction, both in mechanical and electrical engineering, becomes naturally of a more special character, and it may be interesting to place them side by side, for the purpose of comparison.

MECHANICAL ENGINEERING.

THIRD YEAR.

	9.30	10.30	11.30	12.30	1.30	2.0	3.0	4.0	5.0
Monday		Pure Mathematics.	Engineering.	Senior Physics.			Workshop. (Patternmaking.)		
Tuesday		Laboratory. (Testing.)	Applied Mathematics.				Electro-technical Laboratory.		
Wednesday		Pure Mathematics.	Engineering.				Experimental Workshop.		
Thursday		Laboratory. (Preparation.)	Applied Mathematics.				Electro-technical Laboratory.		
Friday		Pure Mathematics.	Engineering.	Senior Physics.			Engineering Design and Drawing.		
Saturday		Laboratory. (Testing.)	Applied Mathematics.						

ELECTRICAL ENGINEERING.

THIRD YEAR.

	9.30	10.30	11.30	12.30	1.30	2.0	3.0	4.0
<i>Monday</i>	Electro-technics.	Pure Mathematics.	Engineering.	Senior Physics.			Engineering Laboratory. (Patternmaking.)	
<i>Tuesday</i>	Engineering Laboratory.		Applied Mathematics.				Electro-technical Laboratory.	
<i>Wednesday</i>	Electro-technics.	Pure Mathematics.	Engineering.				Electro-technical Laboratory.	
<i>Thursday</i>	Electro-technical Laboratory.		Applied Mathematics.				Electro-technical Laboratory.	
<i>Friday</i>	Electro-technics.	Pure Mathematics.	Engineering.	Senior Physics.			Drawing.	
<i>Saturday</i>	Engineering or Electrical Laboratory.		Applied Mathematics.					

It will, however, be seen that in both cases the further study of mathematics and physics, in addition to the more technical subjects, is recommended; and for the purpose of securing the university degree on engineering, or the full college engineering certificate, these courses must be taken.

The subject of university degrees for engineering students is one concerning which there are very divided opinions amongst engineers, and it may be at once remarked that only a very small proportion of the engineering students of the college matriculate as students of the Victoria University, of which Manchester, Leeds, and Liverpool form the three colleges, pass the general preliminary examination of the University, and sit for the final examination for the degree of Bachelor of Science. At the same time, all, or nearly all, the other students who take the course of three years, and are at liberty to choose their own subjects, practically pass through the course of instruction necessary for a university degree, and the proportion of those who do take a degree is increasing. The attendance actually necessary for an Honours degree in engineering at Victoria University is as follows:—1. Engineering, for three hours weekly during the first year, and four hours during the second and third, together with seven hours weekly of practical work. 2. Pure mathematics and applied mathematics each for three hours weekly during the first two years, and either pure or applied during the third year.

3. Chemistry, two hours weekly for one year. 4. Physics or geology, three hours weekly for one year.

So much for the arrangement of lectures, classes, and practical work in the different subjects. A brief account will now be given of the details of the syllabus of the engineering teaching, that is to say, of the actual technical instruction.

From the time tables it will be seen that the time allotted to lectures and classes is for each subject about three hours weekly, one hour being the invariable duration of a class or lecture, the exceptions being the problem class, one hour, and the senior physics, two hours. Concerning the workshop and laboratories more will be said hereafter, but it may be remarked that a student does not necessarily work all the hours which the time table shows to be available, since a certain elasticity is necessary in the arrangement to allow for attendance at extra classes, such as modern languages.

The total time which a student taking a regular course is expected to work in the college is thus from 25 to 30 hours per week, from 15 to 20 hours of this being devoted to lectures and classes, and the rest to practical work, and this, with necessary preparation and private reading, fairly measures the working powers of an ordinary student. Exclusive of the time taken in practical work, engineering lectures and classes thus occupy about one-half the time for all the three courses (*i.e.*, civil, mechanical, and electrical) during the first year, and rather less than one-half for the two remaining years of the course.

In giving the details of the different subjects of instruction, it would be beyond the province of this paper, as well as that of the writer, to discuss the teaching in mathematics, physics, and chemistry. The details will therefore be limited to a consideration of the purely technical instruction, undertaken by the professor of engineering.

It should be noted that a new departure has been made in the opening of an electro-technical laboratory, under Professor Oliver J. Lodge, D.Sc., F.R.S., Lyon Jones Professor of Physics, and the appointment, under him, of a special lecturer in Electro-Technics—Mr. F. G. Bailey, B.A., A.I.E.E.

It has been shown that the work of college teaching is carried on by means of (*A*) lectures and classes; and (*B*) laboratory work.

In the engineering subjects, the lectures and classes are comprised under (1) engineering; (2) engineering, drawing, and design; (3) descriptive geometry; and (4) surveying.

1. There are three lectures a week in engineering to each of the three sets of students, and a problem class of one hour for the benefit of those of the first year's men who need assistance in working out the numerical problems set in the first year lecture course.

Students are expected not only to take notes during the lecture, but to rewrite them in a book, which is brought in once a fortnight for examination by the professor, who inspects and initials such books. These note-books are presented as the students enter the room for a fortnightly examination, which, instead of a lecture, is held on the work done during the previous two weeks. At the following lecture the note-books are returned, and remarks are made upon them by the professor, and also upon the worked-out papers of the students, the proper solutions of the various questions being explained.

The following is the syllabus of the lectures in engineering for each of the three years:—

FIRST YEAR.

AUTUMN TERM.—*Mechanics applied to Elementary Structures and Machines.*

Measurements and units employed for engineering purposes. The principle of end measurement and the preparation of truly plane surfaces. The laws of force and motion, and elementary problems on the dynamics of machines. The principle of work and its application to machines. The nature and action of cutting tools and of machine tools. The nature and laws of friction. Friction on journals, pivots, and thrust bearings. Problems on machines in which friction is considered. Contrivances for reducing the effect of friction, and contrivances such as brakes, friction clutches, friction gear, &c., for its useful application. Friction of ropes and belts. Properties and applications of the screw. The elements of graphic statics as applied to engineering problems.

LENT TERM.—*Elements of Hydro-Mechanics.*

Pressure on quay walls, dock-gates, and embankments. Theory of the steady motion of fluids. Velocity of fluids due to head. Frictional resistances, and loss of head. Discharge from large and small orifices. Viscosity and surface friction. Flow in open channels and loss of velocity by eddies. Stability and resistance of ships. The hydraulic press and hydraulic cranes. Hydraulic motors, water wheels, and turbines. Pumps. The elements of pneumatics. Flow of gases through pipes, air compressors, and cold air machines.

SUMMER TERM.—*Civil and Constructive Engineering.*

Preservation of timber. Artificial stones and hydraulic cements. Brickwork. Masonry. The stability of walls and buttresses. Substructure and foundations. Piles and pile-driving. Cofferdams. Common roads; material, construction, maintenance, and draining. Stone, wood, and asphalt pavement. Railways. Different kinds of rails, their wear and cost. Switches and crossings. Signals, mechanical and electrical. Electrical railways. The elements of bridge construction. Tunnels and embankments. Tramways, the different systems of horse and steam, wire-rope, and electrical traction. Classification of canals. Streams and rivers. Gauging and measuring of velocity at different cross sections. Floods. Different kinds of facings for banks. Construction of dams and weirs. Marine engineering. Sea defences and embankments. Breakwaters. Piers. Harbours. Docks. Supply of water to towns. Rain, spring, well, and river water. Mode of distribution of water supply. Draining of lands and towns. Reclamation and irrigation of land.

SECOND YEAR.

AUTUMN TERM.—*Theory of Machines and Mechanism.*

History of the subject. Definition of a machine. Pairs of elements. Kinematic links and chains. Force and pair closure. Higher pairs of elements. Formulas of the simple machines and of various mechanisms. The theory of machines illustrated by

examples in parallel and straight line motions. Sewing machines. Printing and engraving machines. Shearing machines. Power-looms and spinning machinery. Reversing and quick return motions. The mechanism and mechanical contrivances of the steam-engine and other prime movers. Chamber crank-trains and chamber wheel-trains. Valve motions of various kinds. The theory of toothed wheels. Bevil and screw gearing. Wheels in trains. Epicyclic trains, the transmission of motion by belt and rope gearing. Differential screw and pulley. Apparatus for measuring and for regulating the rates of motion, such as escapements of clocks and watches, and governors.

LENT TERM.—*Prime Movers.*

(1) Sources of energy in nature. The relative values of fuel, wind, rainfall, and the tides for motive power. General considerations concerning the change of energy from one form to another. Efficiency of a motor. (2) Machines for utilising the muscular power of men and animals. (3) Theory of heat-engines. (4) Construction of furnaces, and devices for effecting economical combustion. Transfer of heat from the furnace. (5) Nature and properties of steam. The investigations of Watt and Regnault. Steam-boilers. The expansion of steam in the cylinder. Indicators and indicator diagrams. The inventions of Savory, Newcomen, and Watt. Varieties of engines, stationary, locomotive, and marine. Compound engines. The pulsometer and injector. (6) Hot-air engines. The inventions of Stirling and Ericson, their advantages and disadvantages. Modern improvements in hot-air engines for purposes of small power. (7) Gas-engines. Early failures and modern improvements. (8) Electrical motors.

SUMMER TERM.

An advanced course of lectures will be given during this term upon the elements of bridge construction. An outline of this course is as follows:—

The theory of transverse stresses, including the determination of bending moments and shearing forces by calculation and construction, for beams and cantilevers, with concentrated uniform

and rolling loads, and with travelling load systems. The effect of wind pressure. Stresses in braced structures. The comparative anatomy of girders and bridges. Theoretical weight of bridges and stresses due to the weight of the structure itself. Deflection and curves assumed by girders. Continuous girders under various loadings. Theoretical strength of columns, and the design and construction of struts. Connections by pin and riveted joints. The general question of economic design, and calculations for bridge structures.

THIRD YEAR.

AUTUMN TERM.

A course of lectures will be delivered during this term upon the theory of simple and complex structures, as follows:—

Framework loaded at the joints, including suspension bridges and various kinds of trusses. Straining actions on a loaded structure. Framework in general. The theory of deflection and Clapeyron's theorem of three moments. Compound stresses, including tension and compression with bending and crushing by bending. Formulas of Euler and Gordon. The effect of impact. The ellipse of stress and its applications. Materials strained beyond the elastic limit.

LENT TERM.

A course of lectures will be delivered upon the kinematics and dynamics of machines, as follows:—The construction of diagrams of relative position and velocity for various mechanisms. Problems upon higher pairing, including determination of form of teeth for wheels and form of screw gearing, cams and ratchets, and mechanism in general. The dynamics of the steam-engine curves of crank effort. Fluctuation of energy and speed, and calculations connected with governors and fly-wheels. Efficiency of machines. Straining actions in machines and the balancing of various parts.

SUMMER TERM.

A course of lectures will be delivered upon the theory of the 1892.—ii.

steam-engine and other prime movers, as follows:—The general principles of thermo-dynamics. Calculation of internal and external energy, and thermal efficiency. Properties of steam and permanent gases, and expression of laws which they obey. Theory of heat-engine, working with a perfect gas. Perfect steam-engines. Calculation of the density of steam. Graphical method of ascertaining internal work in expanding steam. Various sources of loss, and effect of clearance and wire-drawing. Action of the sides of the cylinder walls and steam jacketing. Experiments on steam-engines, particularly with triple expansion. Theory and practice of hydro-mechanics, including flow of water in pipes, over weirs, and through sluices, the theory of hydraulic brakes, water-wheels, and turbines. The application of the high-pressure system to the transmission of power.

2. The subject of Engineering Drawing and Design is divided into three courses, A, B, and C, running conjointly to the first, second, and third year's engineering lectures.

In Course A, a weekly lecture is given each Monday on the strength and properties of materials, and the elements of machine design, as follows:—The materials used in machine construction, their strength, properties, and behaviour under the action of loads. The testing of materials, tabulation of, and deductions to be drawn from, such results. Simple problems in connection with forces acting in parts of structures and machines. The strength and form of riveted joints. The dimensions and strength of bolts, nuts, keys, and cotters. The strength and construction of pipes and cylinders. The strength and proportions of shafting and cranks.

In the class which occupies an afternoon in the week, instruction is given in the preparation of tracings and of working and finished drawings.

In Course B, a weekly lecture is given on the effect of live loads, and the researches of Wöhler and Spangenberg, and the formulas of Weyrauch, Launhardt, and others, based upon these researches. The theory and practical calculations required in dealing with the transmission of power by various means, such as by shafting; toothed friction, and screw gearing; belt, rope, and chain gearing. The strength and form of the essential parts

of machinery, such as cranks, levers, connecting rods, cross-heads, pistons, plummer blocks, brackets, &c. The form and dimensions of valves, and design of valve gears.

The above subjects are treated in connection with the class on another afternoon, held on Tuesday, and students are expected to produce finished drawings from data and formulæ given in the lecture. They are taught the methods of copying drawings by photography, as practised in the drawing office.

In Course C, lectures are given upon the design of complete machines and structures, such as steam-engines, turbines, centrifugal pumps, jib and travelling cranes, sheer legs, boilers, retaining walls and dams, girders, masonry and brick arches, roofs.

Students are expected to prepare and complete several sets of designs in connection with certain of the foregoing subjects, and for the college diploma to present at least one such completed set of designs, in the preparation of which the use of text-books will be allowed, but no other assistance.

No terminal certificate in connection with the examinations is awarded to a student in either of the foregoing courses who does not present a satisfactory number of drawings at the end of the term.

3. There are two courses of instruction in descriptive geometry, viz., elementary and advanced. In both courses there is a weekly lecture and an afternoon devoted to drawing. This subject is taught only during the autumn and Lent terms. The elementary course deals with

(1.) *Plane Geometry*.—The construction of scales. The proportion of lines. The description of polygons, and division of areas. The construction of the ellipse, parabola, hyperbola, and other important curves. The transformation of areas. Representation of areas by straight lines. The use of squared paper. Graphic method of finding the centre of like parallel forces. Centre of gravity of simple plane laminae.

(2.) *Solid Geometry*.—The representations of points and lines in space. Representation of oblique planes, and also of simple solids formed by planes, and solids formed by plane figures which revolve about a fixed line. Simple intersection of planes and solids. Use of scales of slope. Developments and simple examples of shadows.

There are during the course a few practical classes in connection with the setting out of work and the actual construction of geometrical forms in sheet metal.

The advanced course deals with

(1.) *Plane Geometry*.—Description of polygons and division of irregular plane areas into any number of equal parts. Construction and use of the logarithmic spiral, trochoids, and other curves. Construction of curves for form of cams to give required motions. Loci in general. Point paths in mechanism. The motions of radial and other valve gears. The elements of graphical calculus, addition, multiplication, the extraction of roots, rectification of circular arcs. Composition and resolution of forces and velocities treated graphically. Centre of parallel forces. Geometrical moment of inertia.

(2.) *Solid Geometry*.—Advanced problems on points, lines, and oblique planes. Intersection of lines with planes, and planes with each other. Representation of solids in any position. Intersection of solids and surfaces. Tangent planes. Scales of slope and their use. Development of surfaces. Isometric projection. Axometric projection. The theory of perspective or radial projection.

The examples in solid geometry will be taken from actual practice, and students will be expected to construct working models in cardboard and sheet metal.

4. There are two courses in surveying, both held only in the summer term.

In the elementary course there is a weekly lecture dealing with the principles of surveying and levelling, including a discussion of the various methods of surveying with chain, telemeter, plane table, compass, sextant, and theodolite, levelling operations and contouring, and the sources of error in levelling.

An afternoon is devoted once or oftener weekly to practical instruction in the use of surveying and levelling instruments, the keeping of field books, the demarcation of survey points, and *field practice* in the neighbourhood, actual surveys being made and plotted.

The advanced course is for second and third year students.

(B.) Laboratory and Workshop Instruction.

The instruction in the workshop and laboratory is arranged according to a progressive scheme to suit the requirements of the three years' course of engineering study.

In the first year students spend four hours in the wood-working department, and before proceeding to actual pattern-making are required to do, satisfactorily, a certain number of exercises at the bench and lathe. Seven hours per week are spent in the main workshop at the vice, lathe, and other tools, and in acquiring some knowledge of forging and moulding, the object in view being to impart an acquaintance with the use of tools, and some idea of working to a drawing.

Students in the second year are required to spend a portion of one morning at pattern-making, of another in the main workshop, and of another in the testing department. They are allowed to prepare test-pieces, and experimental apparatus for their own use. Students of civil and mechanical engineering also take two hours on two other mornings in the workshops, and an additional course of experimental work on applied mechanics.

Students in the third year go through a series of steam-engine trials on the experimental steam-engines, gas-engines, and other motors in the laboratory, thoroughly working out all results. In addition to this, experiments on larger engines are undertaken, with the kind permission of users of power in the neighbourhood. A course of experiments on hydraulics and lubricants is arranged, and also a further course of the testing of materials. The testing machines and workshops are available for carrying out experimental research.

A register of attendance is kept, and leave of absence required, as in the case of lectures.

EVENING INSTRUCTION.

In addition to the foregoing scheme of day instruction there is a comprehensive course of evening work, including advanced lectures for engineers, and a scheme of penny technical lectures for working men and apprentices, of which the following is an outline.

By means of a grant from the City Council, lectures and classes are arranged for working men and apprentices, consisting of:—

(a) Short courses of lectures upon technical subjects.

(b) Lectures and classes on drawing, extending throughout the whole winter session.

The selection of candidates for the penny technical lectures is made by the Working Men's Polytechnic Exhibition Scholarship Committee. Each student not already admitted is required to send in a form of application, signed by himself and by his employer, certifying that he is an apprentice or artisan in receipt of weekly wages, and stating the nature of his employment, and also that he means to attend the whole course with regularity.

(a) The short course of lectures arranged for the coming winter are upon—

(1) The applications of electricity to engineering purposes.

(2) Lines for joiners.

(3) Materials for cutting tools.

(4) Plumbing.

(5) Machine tools.

(6) The elements of electrical science.

The charge for each course of lectures to working men and apprentices is 3d. The charge to others is 1s.; but the number who can be admitted will depend upon the number of selections by the working men's committee.

(b) The drawing courses are as follows:—

(1) Machine drawing and descriptive geometry.

(2) Building construction and drawing.

Tickets for each course of ten lectures and classes, price 10d., are issued on the first evening of each course, and will entitle the student to be present at each subsequent lecture or class.

The charge to others is 6s.

There are, in addition to the above, practical classes in various subjects, such as wood-working, carving, sheet metal work and plumbing; but this paper has already extended to a length which must preclude their detailed consideration.

PLATE I.

WALKER ENGINEERING LABORATORIES.



General View from Brownlow Hill.

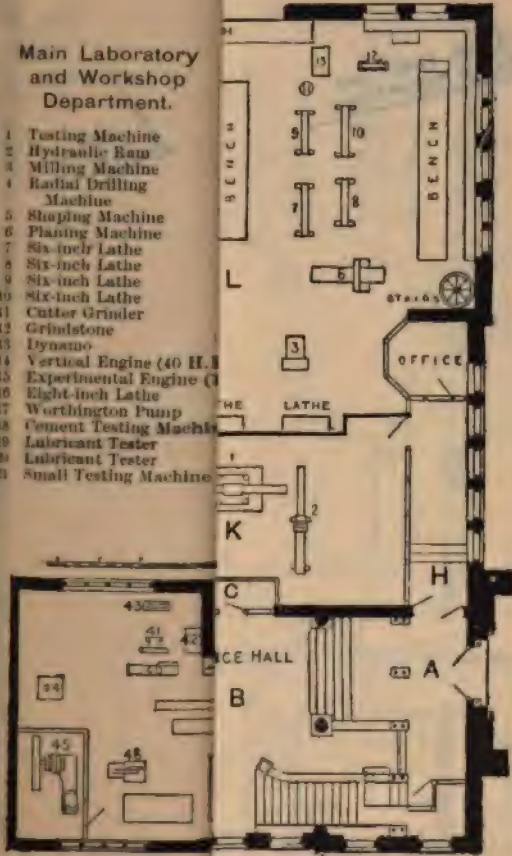
Fig. 1.



PLATE II.

Main Laboratory and Workshop Department.

- 1 Testing Machine
- 2 Hydraulic Ram
- 3 Milling Machine
- 4 Radial Drilling Machine
- 5 Shaping Machine
- 6 Planing Machine
- 7 Six-inch Lathe
- 8 Six-inch Lathe
- 9 Six-inch Lathe
- 10 Six-inch Lathe
- 11 Cutter Grinder
- 12 Grindstone
- 13 Dynamo
- 14 Vertical Engine (40 H.P.)
- 15 Experimental Engine (C)
- 16 Eight-inch Lathe
- 17 Worthington Pump
- 18 Cement Testing Machine
- 19 Lubricant Tester
- 20 Lubricant Tester
- 21 Small Testing Machine





10

VALKER ENGINEERING

THE STAIR



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The PRESIDENT said the Institute was greatly indebted to Mr. Hele-Shaw for having prepared for its special use so interesting an account of a most important institution, of which Liverpool must be proud.

As only an abstract of the paper had been read, full justice had not been done to it; but he hoped that amends would be made for this when the institution was visited on the following day. The paper would be very useful for purposes of reference, as similar papers had proved to be with regard to other educational institutions bearing upon the work of the Iron and Steel Institute. They could not but thank Professor Hele-Shaw for the trouble he had taken.

THURSDAY, SEPTEMBER 22ND.

The Institute resumed its sittings to-day at St. George's Hall—Sir FREDERICK ABEL, K.C.B., F.R.S. (President), again occupying the chair.

The PRESIDENT said that the first paper on the list for the day was by Mr. E. H. Saniter on a new process for the elimination of sulphur from iron. It would be followed by a paper on the same subject by Mr. Stead, and he thought it would be convenient to the meeting to have the two papers read consecutively, the discussion being then taken upon both.

A NEW PROCESS FOR THE PURIFICATION OF IRON AND STEEL FROM SULPHUR.

By E. H. SANITER, F.C.S.

IN September, 1890, I commenced a series of experiments with a view to removing the sulphur from iron.

I was impelled to this research by the recognition of the fact that sulphur was the worst enemy, and the only one, over which the iron and steel manufacturer had not as yet obtained complete control. With this fact in view, I made some experiments to ascertain the effect of prolonged contact of lime with sulphury iron at a high temperature. The results obtained were of an irregular and imperfect character. Reasoning from these results, I came to the conclusion that a more readily decomposable body than lime was necessary for the rapid removal of sulphur from iron. Recognising the fact that chloride of aluminium and other chlorides are readily reducible to the metallic state, I determined to try if calcium chloride, acting in this direction, might not act upon sulphide of iron more readily. Whether calcium is produced or not, I soon discovered that calcium chloride and lime, *i.e.*, the oxychloride, is a very powerful desulphurising reagent.

The following table indicates clearly the comparative results obtained; the sulphury iron being kept molten in plumbago crucibles in contact with the substances named:—

No. of Experiment.	Time during which the molten iron was in contact with the mixture.	Sulphur in iron.		Mixture Used.
		Before Treatment.	After Treatment.	
	Hours.	Per cent.	Per cent.	
4	23	·38	·03	lime
6	13	·30	·12	lime
15	$\frac{1}{2}$	·42	trace	{ lime, 90 %; calcium chloride, 10 %.
16	$\frac{1}{2}$	·42	trace	

These results show (1) that lime alone removes a considerable quantity of sulphur from iron if the contact is sufficiently prolonged. (2.) That a mixture of *calcium chloride and lime*, in the short space of half-an-hour, *completely eliminated the sulphur*.

Further, the lime and chloride of calcium mixture only softened, but did not fuse.

It is upon these last experiments that my process has been elaborated.

It consists essentially in bringing chloride of calcium and lime into contact with molten iron or steel, under certain well-defined conditions. Before proceeding to describe these conditions, it will be desirable to give some information on the important subject of "chloride of calcium." The salt is produced as a *by-product*, to the extent of many thousands of tons, in the manufacture of ammonia, of soda (by the ammonia process), and in Weldon's bleaching powder process. I am informed, on the very best authority, that at the present time not more than 10 per cent. of this large quantity is utilised, the remainder running to waste for want of a market.

The driest calcium chloride obtainable at present contains 70 per cent. calcium chloride, and 30 per cent. of water, and costs about £2 a ton.

Before using, it is generally desirable to dry it, and this may easily and cheaply be accomplished in a reverberatory furnace at a low heat; the whole of the water of calcium chloride being driven off at a temperature of 220° F.

Calcium chloride may also be cheaply produced by mixing "waste pickle," or similar liquors, with lime, and utilising the mixture of calcium chloride, oxide of iron and lime in the basic open-hearth furnace.

Fluor spar, in conjunction with lime, has considerable desulphurising properties, but it has also some considerable disadvantages, viz., its comparative infusibility, and the severe cutting action which it has on the lining, when used in furnaces lined with "basic material."

I now come to the description of the process as applied to the removal of sulphur from raw or cast iron.

A mixture of calcium chloride and lime is prepared, which

will fuse readily at the temperature of the iron to be operated upon.

The desired combination is made by grinding calcium chloride and lime together in a mill so as to thoroughly mix them, and also to bring them to a moderately fine powder.

About equal parts of each are required to give the desired fusibility.

This mixture is then placed on the bottom of a ladle or receiver, and consolidated by heat, or kept in position by other suitable means.

The heat may be applied in the first instance by means of a blowpipe arrangement, using blast furnace gas, but when in continuous use, the heat of the ladle itself is quite sufficient.

The receiver is then filled with iron, which may be drawn direct from the blast furnace, the heat of which melts the mixture, and the latter, rising up through the metal, removes the sulphur very completely.

I do not find it necessary to have reducing conditions, and, indeed, oxidation may be going on concurrently with the removal of the sulphur, as will be seen later on. Notwithstanding this, however, the sulphur is removed as sulphide.

Should it be desirable to remove silicon, as well as sulphur, the lime of the mixture is replaced by hydrate or carbonate of lime, or even oxide of iron in addition, should the hydrate or carbonate be insufficient.

About 25 lbs. of chloride of calcium, and an equal weight of lime, per ton of iron, have been found sufficient to effect purification.

In the many trials made, about three tons of iron, direct from a blast furnace, were treated in a ladle at each operation.

Although the first or coldest iron from the furnace, and hydrate of lime in the mixture, were used, no "skull" was made, which is a fact of the very greatest importance, and there can be no doubt that if such a small quantity of metal is not materially chilled, we may safely assume that larger masses would never "skull."

The uniformity of the results obtained was very marked, as will be seen from the accompanying analyses :—

No.	Class of Iron.	Sulphur.		Silicon.		Mixture Used.
		Before.	After.	Before.	After.	
1	No. 5 hematite	P.cent 220	P.cent 080	Percent. 1.6	Percent. 1.2	Chloride of calcium and hy- drate of lime.
2	Hard forge, 1.5 per cent. phosphorus	300	060	1.7	1.4	
3	Grey forge	070	008	2.2	1.6	" "
4	Basic iron	197	072	Not estimated.		" "
5	"	191	062	"		" "
6	"	109	031	"		" "
7	"	102	032	56	32	" "
8	"	065	026	84	46	" "
9	"	093	016	32	09	" "
10	"	089	024	42	18	" "
11	"	083	020	37	09	" "
12	"	133	030	70	32	" "
13	"	091	026	Not estimated.		Chloride of calcium and limestone.
14	"	060	008	"		

Nos. 7 to 13 are consecutive charges, and show the regularity of the results.

It should be stated that the results shown above were obtained from the application of the process when it was well known, by the appearance of the cinder, that the resulting pig would be abnormally high in sulphur.

The above table shows an average elimination of:—

	Per Cent.
(1.) Sulphur	73.6
(2.) Silicon	35.77

The removal of silicon being due to hydrate of lime only.

The following is an average slag produced by the above treatment:—

	Per Cent.
Calcium chloride	39.1
Calcium sulphide	5.8
Lime	38.6
Silica	12.9

A considerable part of the chloride of calcium in this slag may be dissolved out with water, and recovered for future use.

Only a limited quantity of iron (about 50 tons) has been treated in this way, owing to proper plant not being as yet available, the small 4-ton ladle being only a makeshift. The ladle was lined with ordinary fire-bricks, which were practically unattacked by

the slag at the comparatively low temperature at which the process was conducted.

Appliances are in course of construction which will deal with the whole output of the furnace, as the metal is run.

The plant required is of a simple and inexpensive character, consisting of ladles or receivers on wheels.

The cost of materials at present prices is about 6d. per ton of iron treated, and this cost will be less when a more efficient receiver is used.

It is also very probable that, should a demand arise for chloride of calcium, the price would go down.

Against this extra cost may be set the cheaper production and enhanced price of the pig iron produced.

This process can be adapted to a considerable number of uses, such as:—

(1.) The purification of hæmatite, basic and common (1·5 per cent. P.) irons as they run from the blast furnace or cupola, thus producing these qualities of iron low in sulphur and silicon, after which they might be used for direct steel-making or cast into pigs.

It is a fact pretty well known and established that no sulphur is eliminated in the basic open-hearth process as ordinarily worked, and that not only is this the case, but when ore containing much sulphur is used for feeding, the bath of steel takes up sulphur, so that under these circumstances it may contain twice as much sulphur as that in the pig and scrap originally used. This is shown by Wedding (*Journal of the Iron and Steel Institute*, II., 1890, p. 547), and is confirmed by my own experience.

In my process, however, as applied to the basic open hearth, sulphury iron and minerals may be used, and not only is the sulphur not increased in the steel, but a very considerable elimination takes place.

In order to attain this result, it is necessary, at an early period after the charge is melted, to obtain an exceedingly basic slag, and to add a suitable quantity of calcium chloride to it. By a very basic slag I do not mean what has hitherto been considered as such, but a step in advance of that, with about 50 to 60 per cent. of lime.

If these conditions be obtained and maintained, it will be found

that sulphur is eliminated along with the carbon and phosphorus, and in as satisfactory a manner.

The best method of obtaining this condition of slag is to charge, along with the metal and scrap, a much larger proportion of limestone than usual, about 2 cwt. to the ton. When the charge is melted the slag will be of the required composition, and the chloride of calcium may then be added in several lots, at intervals. The quantity of 70 per cent. chloride used is slightly under $\frac{1}{2}$ cwt. on the ton of ingots made.

The following table shows the quality of iron which has been used, and the steel made from it:—

Pig Iron Used.					Average per cent. of Sulphur in Metals Charged.	Steel Made.				
No.	Si.	S.	P.	Mn.		C.	Si.	S.	P.	Mn.
	P. Cent.	P. Cent.	P. Cent.	P. Cent.		P. Cent.		P. Cent.	P. Cent.	P. Cent.
1	·04	·76	1·3	·18	·58	·215	trace	·081	·027	·68
2	·10	·45	2·1	·50	·35	·20	..	·072	·052	·75
3	·10	·45	2·1	·50	·35	·19	..	·048	·054	·50
4	·04	·25	2·6	1·00	·20	·08	..	·048	·025	·43
5	·20	·23	2·6	1·00	·19	·17	..	·048	·045	·57
6	·20	·22	2·6	1·00	·18	·145	..	·063	·042	·73
7	·20	·22	2·6	1·00	·18	·39	..	·053	·045	·61
8	·40	·22	2·5	1·30	·18	·18	..	·018	·034	·40
9	·20	·17	2·6	1·20	·14	·15	..	·038	·040	·58
10	·18	·16	3·1	1·50	·13	·13	..	·032	·040	·20
11	·44	·15	3·5	1·50	·13	·75	..	·042	·040	·60
12	·20	·15	2·6	1·00	·13	·15	..	·038	·040	·58
13	·65	·13	3·3	1·50	·11	·155	..	·025	·035	·68
14	·56	·05	·05	3·00	·05	·115	..	·016	·010	·12

The pig used in the above charges was 75·0 per cent.

These analyses have been selected to show the varying percentages of sulphur in the cast iron used, and the different grades of steel made. No. 10 is conductivity steel. No. 14, made from white hæmatite, is Swedish bar quality.

The Wigan Coal and Iron Co. have now manufactured over two thousand tons of steel, of which the above are examples, from sulphury iron, the process being continually and successfully worked by them, the sulphur being removed in the steel furnace.

The steel has been sold for all purposes for which basic open-hearth steel is used, namely, wire, hoops, rivet steel, tin bars, &c.,

and has been found to be fully equal in quality to that made from pure pig iron.

It is evident from what has been said that no great care is necessary in the selection of materials, the only objectionable elements being silica and silicon. The commonest descriptions of iron, scrap, and ore may be used, subject to the above reservation. The yield of ingots obtained is as good as that got in the use of low-sulphur iron. The use of common iron, high in sulphur and low in silicon and carbon, has the advantage that a less quantity of steel scrap is required, and that the consumption of ore for feeding is reduced very considerably.

The cost of the chloride of calcium is about 1s. per ton on the weight of ingots, but owing to the saving effected in the cost of materials, and in the quantities of scrap and ore used, there is in reality a saving of about 4s. per ton of ingots.

Neither the hearth nor brick-work of the furnaces, nor the regenerators, are in any way affected by the use of calcium chloride, as has been proved by practical experience over a period of six months.

As it is desirable, in the case of anything new, to have corroborative evidence, I may add that Mr. Stead, on two separate occasions, visited the works of the Wigan Coal and Iron Company, and investigated this process. The results of his investigation confirm what I have stated. I understand the results of Mr. Stead's investigations will be embodied in the paper which he is reading at the present meeting on "The Elimination of Sulphur from Iron."*

The process has been patented in this and other countries.

I cannot conclude this paper without recording my sincerest thanks to Mr. W. H. Hewlett and Mr. T. M. Percy, of the Wigan Coal and Iron Company, who, by their enterprise, and by daily advice and encouragement, have contributed very largely to the attainment of the results laid before you to-day. I have also to thank Mr. Stead (my teacher in chemistry) for much friendly and valuable assistance.

* *Vide* p. 223, *et seq.*

ON THE ELIMINATION OF SULPHUR FROM IRON.

 BY J. E. STEAD, MIDDLESBROUGH.

As there seems to be a wave of scientific thought passing over us at the present time, which has for its object and aim the separation of sulphur from iron, it was believed that the present was a fitting moment to pass in review the work of metallurgists who have studied this question in the past, and to discuss the position we assume at the present time. With this object in view, I venture to lay before you the result of many years' study and investigation, not only of myself, but of others who are worthy of most honourable mention, and whose work will always remain as permanent "footprints on the sands of time"—work which must always be looked upon as a solid foundation for all that has followed. In discussing this important subject, it is necessary to arrange the matter in some systematic order, and I therefore propose briefly to consider:—

1st. The sources whence the sulphur is derived which eventually gets into our pig iron, and the attempts which have been made to remove it from such sources.

2nd. How the sulphur finds its way into combination with iron in the blast furnace, and how it is removed in the same furnace, and eventually finds its way into the slag.

3rd. The changes which are effected in the puddling and other processes depending on the action of oxide of iron in excess when sulphurous iron is operated on.

4th. Sulphur elimination in the acid Bessemer converter and open-hearth furnace.

5th. Sulphur elimination in basic steel processes.

6th. The elimination of sulphur by such processes as those of Heaton, Warner, and others—all of which are based on the action of some alkaline salt upon molten iron.

7th. The Hoerde process of desulphurising.

8th. The most modern and recent discovery of Mr. Ernest Saniter.

It will be seen from this classification that it is proposed to go over a great area, and, to avoid being tedious, I shall endeavour to be as brief as possible.

I.—SULPHUR IN THE MATERIAL.

Coal and Coke.

Sulphur exists naturally in two conditions in coal—1st, in greatest proportion in the pyrites or bisulphide of iron; and 2nd, in sulphate of lime. Some coals are free from the latter substance, but I have met with coal containing as much as 1 per cent., equal to 0.23 per cent. of sulphur.

During the process of coking, half of the sulphur is driven off from the pyrites, but that in the lime sulphate is all retained. It is, therefore, a disadvantage to have sulphate of lime in coal which is required for making furnace coke, but no disadvantage if the coal has to be burned in an open fire, or in the fire-grate of a steam boiler; for the sulphur present in the sulphate is retained in the ash, and none of it escapes into the atmosphere.

During the last twenty years the amount of sulphur, on an average, has been gradually increasing in the best English cokes.

Twenty years ago, the sulphur in the best average Durham furnace coke used in the Cleveland district was not above 0.80 per cent.; and the furnace manager considered himself badly used if a coke containing 1 per cent. was sent to his works. To-day the average coke used in Cleveland contains about 0.95 per cent. sulphur, and coke with 1.25 per cent. is often used. Crushing and washing the coal results in the removal of a very large proportion of the heavy pyrites, and many coals are now so well cleaned by that means as to give a coke well suited for furnace work, which, without washing, would be utterly useless for that purpose.

The removal of sulphur from coal is effected therefore in only two ways:—

- 1st. By washing out the pyrites.
- 2nd. During the coking process.

Iron Ore.

The exceedingly low price of pig iron, and the small profits derived from its manufacture, prohibit the use of expensive processes for the removal of sulphur from the ores. There are only two processes in general use, viz. :—

1st. The method used in America, and only applicable to magnetic ores containing pyrites—viz., the separation by magnetic machines.

2nd. By calcination.

In the first method mentioned it is necessary to crush the ore to fine powder, to pass it afterwards through the magnetic machines, by which means not only are the pyrites separated, but all other substances (such as silica, phosphate of lime, &c.) which are not attracted by the magnet. The ore prepared in this way of course remains in fine powder, and is not in a condition such as we in England care to have it, for our experience with purple ore shows us that when used in large quantities it has a tendency to check the driving in the blast furnace, and that the furnace flues are soon filled with the powder carried over mechanically with the gas.

About twenty-two years ago a cargo of Marbella ore sand was sent to the Witton Park Works. Its condition was exactly similar to that of "magnet" cleaned ore. About 25 per cent. of this cargo was charged, with 75 per cent. of good Spanish ore, into a furnace 75 feet high, working with blast at $3\frac{1}{2}$ lbs. pressure. The result was not satisfactory; the blast refused to pass through the mass with any reasonable speed. As a consequence, the furnace was nearly "gobbed" up, and it was with the greatest difficulty it was got into working order again after removing the cause of mischief. The blast in this case was certainly not great, and I can only account for the reported success in using crushed ore in American furnaces, by the fact that the blast pressure is so much greater. We must not, however, forget that if one evil is reduced by increased blast pressure, the other is likely to be increased, and a correspondingly larger proportion of fine ore is likely to be carried into the flues.

Looking at the question from every point, I am of the opinion that if crushed ores, freed from pyrites, &c., must be used,

large dust-collectors should be attached to the down-comers, and our furnaces must be worked at a greater pressure than is usual in this country, in order to obtain satisfactory results.

Calcination is the most generally adopted method of removing sulphur from ore. At Colebrook, in America, the magnetic ore used in the furnaces is calcined in kilns heated by gas, by which means the sulphur originally present is reduced by 50 per cent.

Purple ore bricks are an instance of the effect of repeated calcination, with free exposure to air, upon iron pyrites, which contains about :—

	Per Cent.
Iron	45.0
Sulphur	50.0
Copper	2.5
Silica, &c.	2.5
	<hr/> 100.0

The greater part of the sulphur is removed in the "sulphur burner," where it combines with oxygen and passes into sulphurous acid (more correctly called sulphur di-oxide), and is eventually converted into sulphuric acid.

When the burnt ore is "drawn," the whole of the original copper, together with 3 to 6 per cent. of sulphur, remains. In this condition it is sent to the copper works, where it is ground to powder, mixed with common salt, and calcined in a reverberatory furnace, in an oxidising atmosphere, by which means the sulphides are oxidised to sulphates.

By washing, the sulphates of copper and other soluble sulphates are removed, and the washed ore, containing 16 to 18 per cent. of water, 0.40 to 0.50 per cent. of sulphur, and 0.08 per cent. of copper, constitutes ordinary purple ore or "Blue Billy."

The sulphur is further reduced to under 0.10 per cent. during the manufacture of bricks, which, after moulding to suitable shapes, are baked in a brick kiln.

If the ores subjected to calcination contain carbonate of lime, its presence is liable to prevent the expulsion of the sulphur by calcination.

Thus, in a careful observation made at Eston, in calcining Cleveland ironstone which contained under 0.30 per cent. sulphur,

the carbonate of lime present was decomposed, and the free lime absorbing the sulphur di-oxide at first produced in the oxidising atmosphere of the kiln, sulphate of lime was produced; and not only was no sulphur removed, but its volume was actually increased, the sulphur from the small coal used for calcining being to a certain extent retained by the lime in the ironstone.

The practice of calcining ironstone and limestone together must result in preventing the escape of sulphur di-oxide.

Sulphur in sulphates of baryta and lime, in fact, sulphur in every form charged into a blast furnace, is equally liable to be retained in the pig iron, for reasons which will be discussed hereafter.

There is no method of removing sulphates from the ore before smelting, excepting by "dressing" and hand-picking, which are only practicable when the white sulphates are not diffused or mixed throughout the material.

II.—REMOVING SULPHUR FROM IRON IN THE BLAST FURNACE.

The following general facts have been so often verified, that they may be accepted without doubt:—

1. That when sufficient lime is present in the furnace charge to combine with all the sulphur and acid (silica), the temperature being sufficiently high, practically all the sulphur will be found in the slag, and little or none in the metal.

2. That if other things remain constant, as the temperature falls, so as to result in pig iron of closer texture or higher number, the sulphur gradually increases with the increasing number until, when the temperature of the furnace is just sufficient to melt the iron reduced, the greater part of the sulphur will be found in the pig, and little will be found in the slag.

3. That the more basic the slag, the less sulphur will eventually be retained in the pig iron.

4. That if manganese is charged with the materials, if the temperature is high enough, less sulphur will pass into the iron, and a proportionately greater amount be found in the slag. Mr. Parry of Ebbw Vale was, I believe, the first to notice this fact. It has since been constantly taken advantage of in producing basic iron in the Cleveland and other districts.

Practically all the sulphur charged into a blast furnace in the

ore, before it reaches the hearth must at one time during its descent have combined with the iron. The experiments and various investigations which follow therefore bear upon the effect of heating together sulphide of iron, or iron containing sulphide, with the substances which are always present in a blast furnace.

Percy (*Iron and Steel*, p. 37) describes an experiment in which he proves that when sulphide of iron is heated at a very high temperature, with lime or baryta and carbon, sulphides of the alkaline earths and cast iron are produced. The same author states that iron sulphide and pure iron unite in very variable proportions, and he gives results of experiments in which homogeneous products, containing about 9.96 per cent. and 14.95 per cent. of sulphur, were obtained by melting together sulphide of iron and iron wire (p. 33). Percy also states that steam decomposes when heated in presence of sulphide of iron, sulphuretted hydrogen being disengaged (p. 35). He adds that when sulphide of iron was heated to whiteness for two and a half hours with charcoal, a small globule of metal was reduced, which was equal to about six per cent. on the total iron treated.

In a second experiment, the globule produced by heating the sulphide to whiteness for three hours, contained 9.41 per cent. of silicon and 89.53 per cent. of iron, and evidently a considerable quantity of sulphur, for sulphuretted hydrogen was evolved on treating it with hydrochloric acid. Now, as there was such a large quantity of silicon in the button, we must assume either that the sulphide was not pure, or that the charcoal used as a lining to the crucibles must have contained silica; the experiment could not therefore represent the effect of C on FeS.

Karsten, on repeating Percy's experiments, found that sulphide of iron is not changed by fusion with carbon. Now, as the two authorities differ so much, it was thought necessary to repeat the experiment a third time; a crucible was therefore brasqued with lamp-black, and about ten grams of sulphide of iron was placed on the bottom, this was covered with lamp-black; and over the whole a fire-clay lid was placed. The crucible was heated to whiteness for an hour and a half; when cold, the crucible was found to be nearly melted away with the intense heat, but no trace of metal could be found, and the sulphide had apparently not suffered any change. The following analyses

indicate the composition of the sulphide before and after the fusion :—

	Before.	After.
Iron	74·8 per cent.	74·3 per cent.
Sulphur	25·4 ..	25·7 ..

Now, although my experiment agrees with that of Karsten, I am not prepared to say that it is impossible to produce cast iron from sulphide by heating it with pure carbon, provided the heat is sufficiently intense.

It is possible that the temperature employed by Dr. Percy may have been greater than in the other cases. Considering, however, that the temperature was described as sufficient to melt wrought iron, and that only about six per cent. of the sulphide was reduced in two and a half hours, we must conclude that, excepting under such conditions as are not likely to occur in any practical smelting process, sulphide of iron is incapable of being reduced by carbon alone to the metallic state.

The next question is, if carbon is incapable of reducing sulphide *per se*, has it the power of removing sulphur from cast iron containing sulphide of iron dissolved in it? Percy answers the question by making an experiment in which white cast iron was fused under charcoal for one and a half hours at a temperature sufficient to melt wrought iron. The result given was as follows :—

	Before.	After.
Sulphur	0·78 per cent.	0·34 per cent.

The white iron was converted into mottled.

Mr. Edw. Riley converted white iron into grey by heating it in a crucible lined with retort carbon, and the sulphur was completely removed. Both Percy and Riley agree to a certain extent; but the removal of sulphur is not so perfect in one case as in the other. An experiment made in my laboratory, using a crucible lining of pure lamp-black instead of impure carbon—such as charcoal or retort carbon, either of which might contain bases capable of combining with sulphur—in which white pig iron, low in carbon, was kept fluid in contact with carbon for an hour and a half at a white heat, resulted in no elimination of sulphur whatever. The same result was obtained when wood charcoal was substituted for lamp-black. The sulphur in the metal was 0·51

per cent., and 0.51 per cent. was found after treatment. There can be no doubt as to the correctness of the analyses, as the sulphurs were determined by two different methods with concordant results. Here, again, my results do not agree with those of other observers, and it would appear as if very slight differences in the conditions under which the experiments are conducted greatly modify the result. My experiments were made at a temperature above that of the hottest product of any blast furnace, and if the heat was greater than this in Percy's and Riley's trials, and if the difference in our results was caused by a greater temperature being employed in the latter, we may assume that the lower degree of heat approximated more closely to what is obtained in blast furnace practice, and that therefore, in the reactions which occur therein, carbon *per se* has little effect in expelling sulphur from iron. This conclusion, however, cannot be accepted as final until it has received much more attention. The iron used in my trials contained nearly 2 per cent. of phosphorus, but I fail to see how that would influence the result.

Iron Sulphide heated with Silica.

Percy gives the result of experiments in his laboratory which indicate that, when sulphide of iron and silica are heated together to whiteness for two hours, no sensible change is effected.

Iron Sulphide heated with Silica and Carbon.

Hochshetter heated iron sulphide, silica, and charcoal together to whiteness for two hours in a covered plumbago crucible, and obtained the following result, viz.:—

<i>Mixture Used.</i>	
Sulphide of iron	600
Silica	600
Charcoal	300
<hr/>	
<i>Product Obtained.</i>	
Iron	Per Cent. 80.23
Silicon	18.77
Sulphur	1.00
<hr/>	
Loss of sulphur	97.46

In this experiment the amount of silicon reduced most clearly indicates the very great heat employed, for it is well known that it is impossible in the blast furnace to obtain such a high percentage of silicon excepting by the use of an extravagant amount of coke, and a very high temperature. To ascertain what result would be obtained if the experiment were conducted at a less elevated temperature, two grams of sulphide were placed on a mixture of lamp-black and silica, and covered with a portion of the same mixture and heated for an hour and a half to a good white heat. The button after the treatment consisted of apparently unaltered sulphide, and no metal was produced. A second experiment was made, using a portion of the same sulphurous white iron as was used in previous experiments instead of sulphide, all other conditions remaining the same as in the last experiment.

The remaining button contained:—

Silicon	5.37 per cent.
Sulphur	0.52 „

Now, judging from the fact that the silicon was reduced to such an extent as 5 per cent., we must admit that the temperature must have been considerable, and that at any rate up to that degree there is no reaction such as Percy found in his experiment when 18 per cent. was reduced.

Turner, in his paper to this Institute, has shown that silicon pigs at their melting-points, containing 13.45 and 10.78 per cent. of silicon, respectively, contained 1.46 and 0.45 per cent. of sulphur, respectively; and that silicon sulphide of iron, containing about 10 per cent. silicon and the same amount of sulphur, on heating to the melting-point of cast iron in a clay crucible, was split up into two perfectly distinct bodies, one containing the greater part of the silicon, while the other was exceptionally rich in sulphur. The metal, however, containing the greater part of the silicon (13.45 per cent.) still contained 1.46 per cent. of sulphur. We may assume, therefore, that, at the temperature mentioned, a stable compound was formed, and that this large quantity of silicon had no power to remove the 1.46 per cent. of sulphur associated with it. In concluding his remarks, he says, "Silicon has the power of expelling sulphur from *cast iron*, and in blast furnace practice there are three chief agencies

at work tending to eliminate sulphur from iron, of which in Cleveland practice not more than one-twentieth passes into the iron—

"1st. A high temperature tends to prevent the absorption of sulphur by iron.

"2nd. A slag rich in lime readily combines with sulphur.

"3rd. The amount of sulphur actually retained by the metal is influenced by the proportion of silicon, and probably also of certain other elements present in the iron."

Now it appears to me that Mr. Turner's experiments show that iron with excessive silicon may still contain 1.46 per cent. of sulphur, an amount exceeding what is usually, in any ordinary cast iron, produced in a blast furnace, and that although his conclusions apply very aptly to compounds of iron, silicon, and sulphur, which have never been met with in practice, they do not apply to ordinary blast furnace work, where the silicon rarely exceeds 5 per cent. Interpreting Mr. Turner's results, it would seem that we are justified in concluding that sulphur is not influenced by the amount of silicon usually present in cast iron. It is well known that silicon pig is produced with a slag deficient in bases, and therefore not well adapted for the absorption of sulphur, and I have found in such iron more sulphur than No. 1 pig iron usually contains, viz., 0.10 per cent., while Mr. Hadfield has stated that out of "fifty to sixty analyses of such iron, containing from 8 to 12 per cent. of silicon, the sulphur has varied from 0.10 to 0.32 per cent.," an amount frequently not exceeded in white iron containing under one per cent. of silicon.

The following analyses represent pig iron produced in blast furnaces working hot, but with deficient lime:—

	White, Per Cent.	Close Gray, Per Cent.
Silicon	1.76	4.27
Sulphur	0.46	0.32

Now, taking all these facts into consideration, we are safe in stating that great and prolonged heat, the consumption of a large quantity of coke in the blast furnace, and the presence of high silicon in the pig, do not, if the lime, or magnesia, or bases capable of absorbing the sulphur are deficient, result in its elimination, or prevent it from being retained in the pig iron.

Many investigators have proved that the carbon is to a greater or less extent expelled from cast iron on the addition of sulphide of iron. It is certain that in all classes of cast iron, no matter at what temperature it is produced in the blast furnace, when the sulphur is high, the carbon will be lower than it would have been had the sulphur been less.

On Smelting Ores containing Barium and Calcium Sulphates.

Barium sulphate (BaSO_4) contains 13.7 per. cent of sulphur. Calcium sulphate (CaSO_4) contains 23.5 per cent. of sulphur.

Many years ago, when experimenting in crucibles with iron ores containing such sulphates in small quantity, it was found that the sulphur appeared quite as liable to pass into the iron as if it had been originally present in the ore as sulphide of iron.

When barium sulphate is present in larger amount, however, it would seem from the records given by Dr. Percy that on smelting such ores in the blast furnace, a regulus consisting of sulphide of iron and barium is formed, which runs off like slag from the surface of the metal.

When these sulphates are heated in a reducing atmosphere, or in contact with heated carbon, they are reduced to their respective sulphides.

In order to ascertain what would result on smelting iron oxide with barium sulphate under different conditions, the following experiments were made:—

Pure Oxide of Iron Smelted with Barium Sulphate and Silicious Matter.

To ascertain the effect of smelting pure kidney hæmatite with barium sulphate and silica, a mixture consisting of—

Hæmatite	50 grms.
Barium sulphate	5 "
Kaolin	5 "
Charcoal	in excess

was reduced in a plumbago crucible, and the resulting button of metal analysed for sulphur, which was found to be:—

Sulphur	1.66 per cent.
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If all the sulphur had been retained by the metal, it should have contained—

Sulphur 1.87 per cent.

This result is exactly what might have been expected, and proves that when there is sufficient silica present to combine with the alkaline earth base, practically all the sulphur will pass into the metal.

Pure Oxide Smelted with Barium Sulphate and Fluor Spar.

On smelting 50 grms. hæmatite ore with 5 grms. barium sulphate and 5 grms. fluor spar, the metal produced contained:—

Sulphur 0.13 per cent.

Pure Oxide Smelted on a Bed of Barium Sulphide.

It was found impracticable to smelt a mixture of oxide of iron and sulphate of barium owing to the infusibility of the barium sulphide produced, and the impossibility of causing a separation of the iron from the sulphide. The oxide of iron was therefore mixed with charcoal, and this having been placed on a layer of barium sulphide, was completely covered with a quantity of the same substance. After the smelting had been effected the metal contained—

Sulphur 0.40 per cent.

Both these trials show that unless silica is present to decompose the sulphide, there is a reduced tendency for the sulphur to pass into the metal.

*Oxide of Iron, Barium Sulphate, Lime, and Fluor Spar,
Smelted together.*

The following mixture, on smelting—

Hæmatite	50 grms.
Barium sulphate	5 "
Lime	5 "
Fluor spar	8 "
Charcoal	in excess

gave metal containing:—

Sulphur 0.06 per cent.

*Oxide of Iron, Barium Sulphate, Lime, and Calcium Chloride
Smelted together.*

The following mixture, on smelting—

Hæmatite	50 grms.
Barium sulphate	5 "
Lime	5 "
Calcium chloride	8 "

yielded metal containing—

Sulphur	0.03 per cent.
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From the results of these experiments, it is clear that the fact that the sulphur from sulphates of the earth metals (when they are present in iron ores), combines with the iron must be mainly due to the effect of silica, which is always present in such ores in sufficient quantity to decompose these sulphates, and thus liberate the sulphur; they also lead us to infer that if the materials charged into our furnaces contained more than sufficient lime to saturate all the silica and sulphur present, and were in intimate contact with them, no matter whether the iron produced was white or grey, it would contain little or no sulphur. Such a condition of things, however, can never be practically obtained. Where fine ore, such as purple ore, containing sulphur, has to be moulded into bricks, lime, if added in sufficient quantity, might, and most probably would, prevent the sulphur from uniting with the iron.

Professor Finkener, of Berlin, upon heating calcium sulphate with metallic iron at a red heat, found that they were transposed into oxide of iron, lime, and sulphate of iron. My authority for this statement is a paragraph in Dr. Wedding's work on the basic Bessemer process, page 191, which is as follows:—

"The fact that iron and calcium sulphate at a red heat transpose into oxide of iron, lime, and sulphide of iron, interferes with the desulphurisation in the basic converter. . . . Professor Finkener, at Berlin, first discovered this."

We are then referred by Dr. Wedding to page 153 of his work on the same subject, where we find the following description of Professor Finkener's experiment:—

"3. Iron and sulphate of lime heated in an exhausted tube.

The mass was melted, and there was formed oxide and sulphide."

It is possible from this second paragraph, that the Professor never intended to convey the meaning put upon it by Dr. Wedding, and that he never determined how the sulphur was associated.

If this is the case, an apology is due to that gentleman from both Dr. Wedding and myself.

As there is evidently some doubt as to what is the natural constitution of a regulus containing calcium, iron, sulphur, and oxygen, it was proposed to make experiments in my laboratory to definitely settle the question, and the following trials were therefore made:—

Sulphide of Iron and Lime, Heated together.

Instead of heating calcium sulphate and metallic iron together, sulphide of iron and lime were substituted.

The sulphide used contained about 36 per cent. of oxide of iron, and about 68 per cent. of FeS. Equal parts of this material and pure lime were most carefully mixed in a powdered condition, and one part of it was heated for an hour in a crucible to a temperature considerably below the melting-point of cast iron, while the other was heated to intense whiteness. When cold, both portions were ground to a fine powder, and an ultimate analysis was made of each, with the following results, viz. :—

	At Low Temperature.		At High Temperature.
	Per Cent.		Per Cent.
Iron	33.90		10.15
Sulphur	12.43		3.38
Lime, oxygen, &c., not determined	53.67	=	86.47
	<u>100.00</u>		<u>100.00</u>

It will be noticed that the composition of the two compounds is widely different, but the reason for this will be readily understood when it is explained, that the mixture which was most strongly heated had combined with a considerable quantity of the lime from the lime-lined crucible in which the experiment was conducted.

For the purpose of our investigation, this addition of lime is, however, of no importance.

In order to ascertain whether the iron was in combination with sulphur or oxygen, advantage was taken of the fact that sulphide of calcium is not affected by heating in dry hydrogen gas, whilst oxide of iron is reduced to the metallic state.

One grm. of each compound was weighed into separate platinum boats, and these were heated in a porcelain tube to bright redness in a stream of dry hydrogen gas, until they ceased to lose weight.

The gas, after passing through the tube in each case, was conveyed through an ammoniacal solution of cadmium for the purpose of absorbing any sulphuretted hydrogen which might be produced. As, however, in neither case was there any of that gas given off, it was clear that any loss sustained by the materials operated upon must be due to oxygen abstracted from the oxide of iron present.

The loss actually was—

From gently heated mixture	= 11.40 per cent.
From strongly heated mixture	= 3.50 "

Now, if all the iron existed as protoxide, and the whole of the oxygen was removed from it, the loss should have been 9.68 per cent. and 2.90 per cent. respectively; but as it exceeded this, it is evident that some peroxide of iron was also present. By computation we find that the iron must have existed in the following states of combination, viz.:—

	Compound Formed at Low Heat.	Compound Formed at White Heat.
Peroxide of iron	17.14 per cent.	5.93 per cent.
Protoxide of iron	23.15 "	7.72 "
	<u>45.30</u> "	<u>13.65</u> "
Iron	33.90 per cent.	10.15 per cent.
Oxygen	11.40 "	3.50 "

These experiments prove conclusively that, both at a high temperature, and at one comparatively low, if sufficient lime is present, it will exist in combination with the sulphur, and that all the iron must exist in combination with oxygen.

Oxide of Iron and Calcium Sulphide, Heated with Silica.

A portion of the same mixture as was used in the last experiments was heated to effect the natural state of combination, and was then mixed with sufficient silver sand to form with the lime a mono-silicate, the mixture being melted in a clay crucible. When cold, it was found, as was naturally expected, that sulphide of iron had formed, and had settled to the bottom of the crucible, and that a well-melted, black, vitreous slag was on its surface.

The sulphide contained—

Iron	76.00 per cent.
Sulphur (by difference)	24.00 "

The slag contained—

Sulphur	0.81 per cent.
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The reaction must therefore have been $\text{FeOCaS} + \text{SiO}_2 = \text{FeS} + \text{CaSiO}_3$.

Iron Free from Sulphur, Heated with Blast Furnace Slag and Silica.

It has been repeatedly demonstrated by many observers that when sulphurous iron is melted with ordinary blast furnace slag, a considerable amount of sulphur is removed from the iron; but as there has been, so far as I know, no trial made to ascertain the effect of making such slag when in contact with iron into one of a highly silicious character by the addition of silica, the following experiment was tried:—

50 grns. of very basic furnace slag,
50 " of silica,
15 " of sulphur-free cast iron,

were mixed together, and were melted in a clay crucible.

The composition of the mixture of slag and silica before melting approximated to the following analysis, viz.:—

Lime and magnesia	26.00 per cent.
Silica	65.50 "
Alumina	7.50 "
Sulphur	0.84 "

The metal and slag, after fusion, were tested for sulphur, with the following result, viz :—

	Metal.		Slag.	
	Before.	After.	Before.	After.
Sulphur .	0·01 per cent.	0·33 per cent.	0·84 per cent.	0·12 per cent.

From this experiment it would appear that not only was sulphur absorbed by the iron, but that a considerable amount must have been volatilised.

It is certain that in furnace practice no such silicious slag is ever produced. This experiment is therefore only of scientific interest, and the result is what might have been expected.

Further experiments are required to determine exactly at what point of silica saturation furnace slags cease to have power to absorb sulphur.

From the soda tank waste trials of Sir L. Bell, it would appear that, in presence of carbon, the same slag has greater power to retain sulphur at high than at low temperatures. In carefully considering the conditions which must have existed in these experiments, it is clear that, in order to flux off the lime, a considerable amount of silicious matter must necessarily have been present (a fact no doubt well known to Sir Lowthian), otherwise no separation of sulphide of iron could have been effected; for if none was present, sulphide of calcium could not possibly have been decomposed, and an increase of temperature would of necessity have produced cast iron and infusible lime, entangled together, so that the furnace would have been closed up.

In order to ascertain what result could be attained in the laboratory, I repeated Sir L. Bell's experiments as nearly as possible, using, however, instead of tank waste and iron oxides, the natural mixture previously referred to, produced by heating equal parts of sulphide of iron and lime together.

Two trials were made—one at a low temperature, the other at a more elevated one.

In each, sufficient charcoal was added to reduce the oxide of iron, and of silica to combine with the lime, and they were both smelted in plumbago crucibles.

The results confirmed those of Sir L. Bell exactly; sulphide of iron separated in the case where low temperature was employed,

and white cast iron, containing 91 per cent. of iron, in the other, but a little sulphide remained undecomposed on the surface of the cast iron.

The Effect of Manganese in the Blast Furnace.

As has been before stated, it would appear that Parry of Ebbw Vale first noticed the coincidence that when manganese ores were used in a blast furnace, sulphur was exceedingly low in the pig, and correspondingly high in the slag. Caron observed the same phenomenon, and since then it has been repeatedly confirmed, and taken advantage of for the purpose of making iron low in sulphur.

Åkerman, in discussing the reason why manganese should have this valuable property, considers that it drags sulphur into the slag even more powerfully than calcium does.

The opinion has been expressed by another gentleman that the manganese in pig iron abhorred sulphur, and the two could not exist together; therefore, as manganese was the stronger element, it expelled the sulphur.

Mr. Snelus explained that it was the oxide of manganese in the slag which, combining with the silica, allowed the lime to act upon and carry off the sulphur.

Howe, discussing this question, says that manganese in some cases actually removes sulphur from iron (probably because sulphide of manganese, like sulphide of calcium, is less soluble in metallic iron than sulphide of iron) by forming a compound rich in sulphur and manganese, which liquates or separates by gravity. This deduction of Mr. Howe is evidently based on the results obtained by Caron, Riley, Ponsard, Walrand, and Ledebur, all of whom proved, that when manganese is added to sulphurous iron in a liquid state, it causes a separation of sulphur from the mixture. Ledebur found that drop-like masses separate from liquid cast iron, and float on the surface, where he found much more manganese and sulphur than in the mass of the metal. The correctness of Howe's deductions has been most perfectly demonstrated at the Hoerde Works, where it has been proved in practice that manganese does combine with sulphur, and rises by gravity, in the state of manganese sulphide, when the two elements are brought together in fluid cast iron.

From the above considerations, we may safely grant that the effect of manganese in the blast furnace in removing sulphur, to a certain extent depends on a portion of the manganese at first reduced entering the metal, where it combines with the sulphur, and, leaving the metal again, carries it off to the slag as sulphide of manganese.

There are cases on record, given by Tucker and Harbord, in which they found blast furnace metal containing large amounts of both manganese and sulphur together.

	Per Cent.	Per Cent.	Per Cent.
Manganese	2.26	2.54	1.76
Sulphur	0.20	0.11	0.42

Such a series of metals, we must admit, is most exceptional. It is possible that so much sulphur and manganese existing together in the same pig iron may be accounted for by assuming that the furnace in which they were smelted was producing, on one side, highly manganiferous iron, and, on the other, sulphurous iron, low in manganese, that perfect mixing had not been effected at the time the metal was tapped, and that when they eventually left the furnace, sufficient time was not given to admit of the separation of the sulphide of manganese before it became solid in the pigs.

If such iron could be re-melted, and allowed to remain fluid for a sufficient time, in all probability separation would result.

Blast Furnace Slags, and their Effect on Iron containing Sulphur.

It is a very well recognised fact, that the more basic a blast furnace slag is—other things remaining constant—the greater will be the amount of sulphur found in it, and that the greater the quantity of slag, the more perfectly will it retain the sulphur. As an instance, the practice in Cleveland may be quoted.

In making Cleveland pig, the ore contains 0.3 to 0.5 per cent. sulphur, and the quantity of slag per ton of pig thrown off amounts to about 30 cwts., while it is far from being very basic; and yet the metal produced contains no more sulphur than hæmatite iron made from ores containing practically no sulphur, which, however, is produced with much more basic slags, weighing under 15 cwts. per ton.

Sir L. Bell converted white iron into grey by exposing it for a long time under the hot slag which flowed from a furnace making No. 3 iron. I do not remember whether or not analyses of the material before and after treatment are on record; but I should assume that the hot slag must have removed the sulphur from the white iron.

Ledebur melted cast iron containing 2.33 per cent. sulphur with mono- and bi-silicate of lime, and obtained the following result:—

	100 Pig Melted with			
	200 Per Cent. CaSiO ₃ .	200 Per Cent. CaO(SiO ₂) ₂ .	200 Per Cent. MgSiO ₃ .	200 Per Cent. MgO(SiO ₂) ₂ .
Sulphur in pig	0.079	0.357	0.269	0.290
Percentage in slag	1.445	0.681	1.069	0.29

No mention is made of silicon.

From the above results it will be seen that the more basic slags removed the greater amount of sulphur, and that lime is a much more powerful desulphuriser than magnesia.*

Turner melted silicious white iron containing—

	Per Cent.
Silicon	4.17
Sulphur	0.446

and found no change by simply fusing it, but on melting it under Clarence slag, the sulphur was reduced to 0.186 per cent.

All these experiments clearly prove what desulphurising power slightly basic silicates possess; yet Janoyer found on the large scale in the blast furnace that "when iron pyrites existed in sensible proportion even with excess of lime, he could not produce good grey iron. The sulphur in the iron was found to diminish in proportion to the amount of lime added or *ceteris paribus*, but it was impossible to add sufficient lime to effect complete desulphurisation and at the same time produce a fusible slag." Unfortunately all the conditions are not recorded, and we are not told what quantity of pyrites was actually present. Howe* says that the practice at the Illinois Iron Works proved that when dolomite (magnesium limestone) was replaced by calcite (ordinary limestone) less sulphur was found in the metal, showing that lime is a more efficient desulphuriser than magnesia.

* Howe, *Metallurgy of Steel*.

Magnesium limestone has never been used successfully in smelting Cleveland iron. Whenever a trial has been made with it, the iron has invariably changed from grey to mottled or white, and the sulphur has been increased in the pig; the slag at the same time changing in character from a free flowing to a viscous material.

In the manufacture of Bessemer iron, magnesium stone has given better results, but in one or two cases, after a trial, it was abandoned in favour of limestone. There is no objection to its use in furnaces producing spiegel and ferromanganese, as the manganese is sufficient to remove the sulphur, and there is an advantage, in that the slags may be exceedingly basic and yet not disintegrate when cold.

From what has been stated, it is clear that by far the most potent agencies at work in a blast furnace for the removal of sulphur are a sufficiently elevated temperature accompanied by a sufficient quantity of basic silicate of lime. So far as I know, alumina is inert as a desulphuriser, but its presence in the slag causes it to be more fluid, and makes it possible to add a greater quantity of lime without rendering the slag viscous and thick, and although not a direct agent in removing sulphur, it assists indirectly in arriving at such a result.

How the Sulphur Behaves in the Blast Furnace.

We must now endeavour to follow the material containing sulphur, from the time it is charged at the top of the furnace, till it eventually comes out at the base. At first, when the temperature is considerably below redness, the sulphates of lime and baryta, if present, will not be materially affected; when it arrives at the point where the temperature approaches redness, these bodies will be reduced to their respective sulphides, and at a point below this, when the temperature is high enough to produce the lowest quality of white iron capable of being fluid, whether at the tuyeres or at some distance above (the distance depending on the quality of the iron being made), we may presume such fluid iron will have in combination with it the greater part of the sulphur originally present in the ore, whether it existed in barium or calcium sulphates, or as sulphide of iron.

As little of the coke is consumed before it comes in contact with the blast near the hearth, the sulphur in it in a great measure may be considered to be locked up, and not until the carbon is burnt away has it a chance of passing into the fluid iron.

Now in proportion as the temperature is more or less elevated, so also will the reducing power of the coke or carbon be greater or less, and the higher it is, the greater will be the distance above the tuyeres at which fluid cast iron is at first produced, and the greater the distance which such iron will have to travel before it reaches the hearth or well. During such passage it will be exposed to higher and still higher temperatures, encountering everywhere surrounding it hot carbon, lime, and basic silicates; under circumstances like these we can readily understand how sulphur passes into the slag. If the reducing power is sufficient, and the necessary quantity of lime or basic silicates is at hand, more or less of these silicates will be reduced, the silicon uniting with the iron, and the base metal made available for at once removing the sulphur. In this way it will be seen the conditions which favour the reduction of silica are also, if bases are present (and they almost invariably are) just the conditions necessary for removing the sulphur. Probably the sulphur from the coke, in a hot furnace, in presence of calcareous slags and intensely heated carbon, combines with the bases almost at once and never enters the metal; for both free sulphur and sulphurous acid, if passed over a mixture of carbon and lime at a strong heat, are absorbed, calcium sulphide and carbonic oxide resulting. On the other hand, if the temperature is low, although perhaps half the sulphur may be retained in the slag, the balance will be found in the metal.

In making a very low quality of pig iron, its fusion point must be very near to the tuyeres; for if a furnace working in such a condition is slightly cooled below the already low temperature, the hearth will be closed up by the solidification of the metal and slag, the temperature falling in such a case below the melting-point of the iron.

Further investigations are required to determine definitely and exhaustively the question as to the behaviour of sulphur in a blast furnace, at least so far as the chemical changes are concerned.

III.—DESULPHURISING IN THE PUDDLING AND OTHER PROCESSES DEPENDING ON THE ACTION OF FLUID BASIC IRON SILICATES.

Dr. Percy says, with regard to the elimination of sulphur in the puddling furnace, it "is always, as far as my knowledge extends, very imperfect. It may possibly be oxidised with the oxygen of the air, but some of it appears to pass into the cinder in the state of sulphide of iron." *

Practically all other investigators have re-echoed in substance the views of Dr. Percy, and nobody seems to have given the question the serious consideration it deserves.

Parry states "that in his experience the effect of puddling is to reduce the original sulphur to about one-third."

Mr. Snelus, in his report on the Danks' process, has clearly shown, that the amount removed in a very great measure depends on the original quantity; we find that when the sulphur was exceedingly low (0.03 per cent.), there was no elimination whatever, but that when the quantity reached .76 per cent. the amount removed was 90 per cent.

Harbord has calculated, from the results given by very many investigators, that on an average 55 per cent. of sulphur passes off, and that the amount greatly depends on the quality of the cinder.

My own experience with the ordinary puddling process confirms exactly that of Mr. Snelus.

In the old days it was a common practice to puddle iron containing from 0.50 per cent. to 0.70 per cent. sulphur, and yet the puddled bar rarely contained 0.10 per cent., the average approximating more closely to 0.07 per cent., some of which must have been in the cinder entangled in the bar, and not combined with the iron.

On one occasion, during a strike of limestone men, the furnace manager at Witton Park was reduced to the necessity of substituting blast furnace slag for limestone. The result, as expected, was pig iron charged with nearly the whole of the sulphur of the materials, amounting to from 1 to 1.25 per cent.

It was in fracture a fine silvery white. The silicon had remained normal (at 1 per cent.), and had not increased as it was expected it would. This pig puzzled the puddler; he could not

* Percy's *Iron and Steel* (pp. 663-666).

get it to ball up, and, as was customary in those days, he struck work.

Some of the bar, made after very careful handling at the hammer, contained a little over 0·12 per cent. of sulphur; there had therefore been an elimination of about 90 per cent.

The Washing Process of Sir Lowthian Bell.

This process consisted in agitating together in a suitable furnace molten oxides of iron and fluid iron. The following results were obtained with the iron before and after treatment (*Journal of Iron and Steel Institute*, No. I. 1887)—

	Before. Per Cent.	After. Per Cent.
Carbon	8·264	1·273
Silicon	1·493	0·009
Sulphur	0·113	0·024
Phosphorus	1·516	0·065

Amount of sulphur removed, 78 per cent.

Krupp's Process.

This process, very similar to Bell's, but patented two months later, depends on the action of an oxide of iron and manganese lining, in a rotary furnace, upon molten iron, which action is discontinued before the carbon is materially acted upon. Analyses given by Holley show that at Krupp's works the following changes were effected :—

	Pig Used.	Refined Iron.
Carbon	3·30 per cent.	3·22 per cent.
Silicon	0·39 „	0·023 „
Phosphorus	0·74 „	0·106 „
Sulphur	0·09 „	0·029 „
Manganese	2·32 „	0·058 „

The oxides used amounted to about 14 per cent. Had all the sulphur remained in the slag, it should have contained about 0·42 per cent., whereas analysis recorded only 0·08 per cent.

Amount of sulphur removed 68 per cent.

The large amount of manganese present in the iron is probably responsible for the elimination of part of the sulphur.

Henderson's Process.

In this process, the base or hearth of the furnace was covered with a mixture of fluor spar and oxide of iron, both in powder; and

upon this cast iron was poured. The heat of the metal melted the mixture, which, passing upwards, removed silicon, sulphur, and phosphorus, and part of the carbon.

The amount of sulphur removed appeared, by the analysis given, to vary; but indicated a sulphur elimination between *nil*, in very pure iron, to about 99 per cent. in iron high in sulphur.

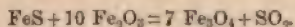
It would appear that, in this process, the oxide of iron is responsible for the elimination of the sulphur; but it is probable that the fluor spar may have had some effect.

Practically, then, all these processes depend on the action of *fluid* oxides of iron or of basic silicates or phosphates of iron; for we may take it for granted that in these cases where the liquid iron is heated in contact with the solid fettling, the latter is actually fused before it can have much effect.

The chemical changes we may therefore consider to be the same in each case.

We must note, however, as before mentioned, that the very high percentage of manganese in the Krupp metal must have itself effected a considerable desulphurising action, and that in this process the oxides of iron are not alone responsible for the elimination of the sulphur.

Percy has shown that, by heating sulphide of iron with peroxide of iron in a clay crucible, the oxygen, over and above what is required to convert all the iron into magnetic oxide, oxidises the sulphur which escapes as sulphurous acid.



As this result was obtained by melting the mixture in a clay crucible, it is probable that the oxides would form silicates with the material of which the crucible was made, and is therefore open to objection.

From another experiment, made in Percy's laboratory, it would appear that if an excess of sulphide is melted with peroxide of iron, a homogeneous mass, consisting of iron oxide, and sulphide of iron dissolved in it, is obtained. The analysis, unfortunately, is not given.

Finkener melted sulphide of iron and protoxide of iron in a platinum boat in a tube exhausted of air; "the mixture was

completely melted, the platinum boat eaten through, and the tube fused."

Wedding says "that sulphide of iron in association with magnetic oxide is stable." ("Basic Bessemer Process," p. 191.)

The most conclusive evidence as to the stability of mixtures of oxides and sulphides of iron was obtained during trials which were made in working the Hollway process of blowing air through fluid sulphide of iron containing some copper in presence of sand or silica.

When the silica was deficient in quantity, a slag of the following approximate composition was obtained, which was quite homogeneous:—

	Per Cent.
Iron	64.11
Sulphur	15.82
Silica	4.65
Oxygen, &c., by difference	15.42
	<hr/> 100.00

Analysis of the ordinary slag, consisting (when almost fully saturated with silica) essentially of protosilicate of iron, contained, dissolved and evidently combined in the mass, sulphide of iron equal to from 3 to 5 per cent. of sulphur. When, however, this slag was oxidised so as to produce a considerable quantity of peroxide of iron, the whole of the sulphur passed off, most probably as sulphurous acid.

Slags Produced in Working Hollway's Process.

	Protosilicate.	Protosilicate Oxidised.
	Per Cent.	Per Cent.
Silica	30.05	34.34
Iron protoxide	54.62	25.10
Iron peroxide	3.71	33.83
Iron	4.27	...
Manganese protoxide	0.37	0.12
Alumina	2.06	1.81
Zinc oxide	1.75	0.73
Copper oxide	0.22	2.39
Lead oxide	0.10	0.03
Lime	0.37	0.24
Magnesia	0.45	0.30
Sulphur	2.55	0.15
Arsenic	Trace	None.
Phosphoric acid . . . . .	...	0.031
Oxygen, &c., not estimated . . . . .	...	1.45

The fact that basic silicates of iron can dissolve sulphide of iron is evident also from the analyses of the puddling and analogous slags, nearly all of which show the presence of iron sulphide in amounts varying from 0.24 per cent. to 3 per cent.

It has been proved by Parry, Snelus, myself, and others, that in purification with basic silicates of iron, some of the original sulphur remains in the slag as sulphide of iron, and some of it passes away as sulphurous acid gas.

Taking all these facts into consideration, it would seem that there can be only two possible explanations of the removal of sulphur from the fluid iron by molten iron silicates.

1st. That the attraction of the cinder for iron sulphide is greater than that of the iron, and that it is simply washed out of the iron, and in part retained in the slag, the other part, after removal as sulphide, being oxidised to sulphurous acid by the free oxygen always present in the hearth of the puddling furnace, or by the water vapour from the coal.

2nd. That the peroxide of iron in the cinder acts directly on the sulphur in the iron, oxidising it to SO_2 .

In accepting the second hypothesis, we must assume either that the whole of the sulphurous acid escapes (in which case no sulphur would be retained in the slag), or that it partly suffers reduction after it leaves the iron, and by some unexplainable reaction it again combines with iron, forms sulphide, and dissolves or combines with the basic silicates.

An endeavour to ascertain the nature of these changes was made in my laboratory, but it was soon found that, on a small scale, it was almost impossible in a crucible experiment, with ordinary fluid cast iron and cinder, to obtain satisfactory results, as the iron so rapidly begins to boil, and so soon sets into solid particles. A compound of the following composition was therefore prepared, containing no silicon or carbon, but sufficient phosphorus to keep the mass fluid at a comparatively low temperature:—

<i>Sulpho-phosphide of Iron—</i>		Per Cent.
Iron	.	90.70
Phosphorus	.	7.10
Sulphur	.	1.86

A basic silicate of iron, made by melting together steel scale

from a "rod mill," and sand in a clay crucible, was also prepared.

A small quantity of the phosphide was shaken when liquid with the fluid cinder, in a crucible which was removed from the fire just before the experiment was made. During the agitation apparently no gas was given off, and no odour of sulphurous acid could be detected.

After shaking for about one minute, the still fluid contents of the crucible were poured into a mould, and, when quite cold, both the cinder and iron were analysed.

The quantity of cinder was greatly in excess of the sulphophosphide. The analyses were as follows:—

	Cinder.		Metal.	
	Before. Per Cent.	After. Per Cent.	Before. Per Cent.	After. Per Cent.
Sulphur	0.06	0.27	1.86	0.27

Judging from this imperfect experiment, it would appear that no perceptible amount of SO_2 was evolved, although a considerable amount of sulphur was removed from the metal. The existence of sulphur in the slag, which, previously to bringing it in contact with the metal, was in very small proportion, would rather favour the theory that sulphide of iron is actually washed out of the metal and not oxidised directly. This question is receiving more attention, and I hope before long to have more reliable and conclusive results to place before you.

IV.—SULPHUR IN ACID STEEL-MAKING PROCESSES.

Wedding (page 143 of his work on "The Basic Bessemer Process") says: "It is well known that in the acid Bessemer process sulphur is evolved in considerable quantity, as sulphurous acid, because iron sulphide, silica, and carbon change into carbon-silicon-iron and sulphurous acid. In this way from 92.8 per cent. to 97.5 per cent. of sulphur can be removed."

Sir L. Bell, in his "Principles of the Manufacture of Iron and Steel" (page 423), gives analyses of the changes which occur in this process, indicating practically little or no sulphur elimination, and I believe that this conclusion has been arrived at by other careful observers.

At the various works where I have had the opportunity of

testing the metal before and after blowing in the converter, it has always been shown that there was not a less quantity in the steel.

When the metal is melted in a cupola furnace, preparatory to blowing it, sulphur is absorbed from the fuel to the extent of from 0.01 to 0.06 per cent., the quantity depending on the amount and quality of the coke, and to a certain extent on the proportion of limestone used as a flux; and it is a fact that in ordinary English practice, when working in this way, the sulphur is higher in the steel than in the original metal. Howe says that White, of the Bethlehem Steel Works, America, found more sulphur in the steel than was in the metal run into the converter, no doubt due to the concentration, and the absence of any elimination.

Sir L. Bell, in blowing Cleveland iron at Spennymoor, found no elimination of sulphur.

Snelus, at Dowlais, in working pig with 0.014 per cent., found only a trace in the steel. As, however, there was practically only a trace to commence with, the conditions can scarcely be taken as suitable for ascertaining the behaviour of the sulphur in metal blown in a converter.

Baker, at Sheffield, found that the metal charged, containing 0.107 per cent., was reduced to 0.093 per cent. at the termination of the blow.

At Seraing, metal containing 3.75 per cent. Mn., and 0.04 per cent. sulphur, suffered no diminution of sulphur during conversion in the Bessemer converter.

If we take into consideration the concentration occasioned by the combustion of some of the constituents of the metal, it would appear that, although the sulphur remains the same in relation to the mass of metal and steel, there must be an elimination equal to the loss of metal in blowing, and this amounts to about 10 to 11 per cent. This elimination may be accounted for by the effect of manganese in the metal, either naturally present or added with the spiegel and ferro.

With regard to the theory that silica oxidises the sulphur during the first part of the blow, I am afraid we must abandon it, first, because in reality there never is free silica present when the silicon is oxidised, for it is well known that the magnetic or other oxides at first produced near the tuyeres are the main agents at

work in removing silicon, and this they do at their own expense, as they are partially reduced, iron and silicate of iron, and not free silica resulting; and again, for reasons previously advanced, even if free silica was present, the temperature at the early stage of the blow is not sufficiently high, nor the time of exposure long enough, to be at all comparable with the conditions of the experiments made in Dr. Percy's laboratory.

V.—SULPHUR IN THE OPEN-HEARTH ACID PROCESS.

Snelus, Hardisty, and many other observers have noticed that, in the acid open-hearth furnace, there is no elimination of sulphur, but that sulphur is actually absorbed frequently from the furnace gases, and thereby materially increased in the steel.

My experience is that in working with the purest material containing only 0.01 per cent. sulphur, the steel contains from 0.025 per cent. to 0.040 per cent. sulphur. Sulphur is absorbed from the sulphurous acid in the furnace gases, and if it is present in the ore charged to oxidise the bath, a portion at least will pass into the steel.

Willis found that 30 per cent. of the sulphur in ore containing sulphate of baryta passed into the steel. (*Iron and Steel Institute Journal*, 1890.)

The silicious slag always present in contact with the bath of metal approximates closely to what is first produced in burning out the silicon in a Bessemer converter, and the fact that it has no action whatever on the sulphur in the metal demolishes completely the theory that it has any effect in that direction in the converter.

Sulphur in the Basic Processes.

Herr Massenez and Professor Finkener in Germany, and nearly all observers in this and other countries, are agreed, as indicated by the analyses they have published, that there is a notable quantity of sulphur removed in the basic Bessemer converter.

Professor Finkener found that in blowing metal containing 0.08 per cent. and 1.0 per cent. manganese, in $2\frac{1}{2}$ minutes it was reduced to 0.047 per cent., after which it steadily increased till it

amounted to 0.055 per cent. at the end of the blow; but after the addition of spiegel and ferro-manganese, it fell to 0.045 per cent. At Hoerde, in blowing iron containing 0.42 per cent. sulphur, and only 0.41 per cent. manganese, the sulphur was not apparently reduced till the after-blow was half completed, when it was reduced to 0.26 per cent., and to 0.15 per cent. after the addition of spiegel and ferro-manganese.

At Eston, when ordinary Cleveland iron was blown, I found that where only 0.05 per cent. sulphur was originally present, it remained constant, but that in blowing metal with 0.16 per cent. sulphur, it was steadily eliminated till it reached 0.10 per cent.

Kupelwieser found that in blowing metal at Hoerde the sulphur increased as the conversion progressed from 0.152 per cent. to 0.206 per cent., but that it diminished to 0.133 per cent. after adding the spiegeleisen and ferro-manganese. At Witkowitz he found the same amount of sulphur in the steel as was present in the pig.

Wedding (p. 154) states that at Creusot, by continuing the blow after the phosphorus is removed, the sulphur in the pig is reduced from 0.2 per cent. to 0.03 per cent.

Mr. C. H. Ridsdale informs me that, after long experience, he has found that, at the North-Eastern Steel Works, the sulphur on an average is diminished by about 0.03 per cent. from metal containing about 0.09 per cent., the initial amount of manganese being about 1½ per cent.

Sir L. Bell gives analyses made in his laboratory of the results obtained by blowing white iron at Hoerde, which show an elimination of 73 per cent. of the sulphur present. This, however, must be taken as exceptional.

On examining all these results, excepting those of Kupelwieser, we find that when the proportion of sulphur is considerable, the amount eliminated is much greater than when it is present in less amount; thus, without taking into account concentration by loss in blowing:—

With 0.42 per cent. in the pig, the steel contains 0.15 per cent., or 64 per cent. less.

0.307	"	"	"	"	0.85	"	or 73	"	"
0.160	"	"	"	"	0.10	"	or 37	"	"
0.09	"	"	"	"	0.06	"	or 33	"	"
0.05	"	"	"	"	0.05	"	or no change	"	"

Allowing, however, for the loss in blowing, the proportions given above must be increased by about 15 per cent. more or less.

Wedding * says the fact that manganese additions at the termination of the blow caused a diminution of sulphur, need not create surprise, "since it is well known that the manganese induces a removal of sulphur."

Again, he states that "S actually volatilises from the vessel is indicated by the fact that the slags from highly sulphurous charges contain no proportional increase of CaS, so that the elimination of S from the metal exceeds what is thus accounted for in the slag."

Sulphur in the Basic-Hearth Process.

Mr. Harbord, in his paper on the basic open-hearth process, read before this Institute, shows that in working charges containing high sulphur, the amount eliminated varies between 45 per cent. and 50 per cent :—

	Metal.	Steel.	Removed.
	Per Cent.	Per Cent.	Per Cent.
Sulphur	0·23	0·125	45
"	0·18	0·089	50
"	0·40	0·200	50

Mr. Hardisty has kindly given me the following information, obtained as the result of his experience :—

	Metal Con- taining	Steel Con- taining	Eliminated.
	Per Cent.	Per Cent.	Per Cent.
Sulphur	0·22	0·15	31
"	0·15	0·11	26
"	0·10	0·065	34
"	0·07	0·050	30
"	0·04	0·025	37
"	0·025	0·015	40
Average . . . . .	...	...	33

* *Iron and Steel Institute Journal*, 1890, vol. ii. p. 539.

Yet Wedding* says: "It is to be noted that the basic open-hearth process removes little or no S, so that its product averages relatively more sulphur than does converter metal." This is also the experience of Mr. Saniter and others. We may therefore assume that the results of Hardisty and Harbord are exceptional. Wedding also gives results, showing that near the end of the process, the sulphur increases in the case quoted from 0.067 per cent. to 0.087 per cent. He also says, "Apparently open-hearth metal is less affected in its physical qualities by S than converter metal."

In discussing the changes which occur in the basic Bessemer process, Professor Finkener states that "it is impossible to remove sulphur as sulphate of lime, for that body is reduced by iron, sulphide and oxide of iron and lime resulting, and that other sulphur compounds, when they are formed, are decomposed by iron."

Wedding (p. 154) says: "If the action of sulphur in the blast furnace can be compared to its action in the acid and basic Bessemer process, it follows that a sulphur separation can take place with calcium and manganese, because the oxidising effect of the oxygen fails; in the acid process the oxidising effect of the oxygen adds to that of the free silica, while in the basic process these two conditions fail, and therefore a low sulphur content conditions a favourable result."

Later, however, Wedding says that "in converting basic iron in a converter, the S is not reduced till the after-blow." He adds: "Many special investigations have proved that during the dephosphorisation manganese returns to the metal bath, where it effects an elimination of sulphur."†

Now, with all these facts before us—with the theories of Wedding and Finkener, and the fact that lime alone, and calcareous slags, are capable of removing sulphur from iron, it would seem that what desulphurisation is effected in the basic process results from one or a combination of four causes:—

1. That the manganese added in the metal, in passing out, may carry some sulphur with it.

* *Iron and Steel Journal*, 1890, vol. ii.

† *Ibid.*, p. 599.

2. That the manganese reduced from the slag during dephosphorisation effects an elimination of sulphur.

3. That the calcareous slag in contact with the upper surface of the bath containing carbon, may absorb sulphur.

4. That some of the manganese added in the ferro does undoubtedly leave the bath again, carrying with it a small quantity of sulphur.

The changes during elimination of the sulphur in the basic process, however, have not yet been thoroughly explained, and the subject is worthy of more attention.

Rollet's Process.

Rollet has made many and exhaustive experiments to desulphurise iron. His process consists "in melting pig iron and maintaining it at a very high temperature under a double action, slightly reducing and slightly oxidising, in the presence of a slag obtained by admixtures of limestone (or lime), iron ores, and fluor spar, in proportions depending on the quality of the pig or castings employed."

He says "the elimination of the sulphur is complete up to 99 per cent., and even more."

The process is conducted in a jacketed or basic-lined cupola furnace, and coke is used as a fuel; a large excess of lime, and from $2\frac{1}{2}$ to 4.8 per cent. of fluor spar is used, so that the slag does not contain more than 2 per cent. of silica.

I have not had an opportunity of investigating this process, and cannot therefore explain why it is that the sulphur passes out of the metal. As, however, both Mr. Saniter and I have found that lime alone will desulphurise iron, it is probable that the very calcareous slag employed is in greatest measure responsible for the elimination.

VI.—DESULPHURISING WITH ALKALINE SALTS.

Heaton's Process.

This was based on the oxidising action of nitrate of soda, upon which, after being placed on the base of a suitable receiver,

and kept in place by a grating of iron, fluid iron was poured. The oxygen of the nitrate instantly acted upon the iron, removing some of the phosphorus, all the silicon, and nearly all the sulphur.

Professor Miller gave the following results of analyses of three samples of metal produced at the Langley Mills under his own observation :—

	Cupola Pig.	Crude Steel.	Steel Iron.
	Per Cent.	Per Cent.	Per Cent.
Carbon	2·830	1·800	0·993
Silicon, with a little titanium	2·950	0·266	0·149
Sulphur	0·113	0·018	Traces.
Phosphorus	1·455	0·298	0·292
Arsenic	0·041	0·039	0·024
Manganese	0·318	0·090	0·088

Mr. Snelus practically confirmed Professor Miller's analysis, and found a considerable quantity of sulphate of soda in the slag, resulting probably from the action of the nitrate upon the sulphur in the iron. On a small scale, in my own laboratory, I have also found that the sulphur is completely removed by nitrate of soda.

Warner's Process.

This process is conducted in a receiver, similar to that of Heaton, but instead of nitrate of soda, a mixture of ground limestone and soda ash, and small quantities of other materials, are placed on the bottom. About ten minutes after the metal is poured in the reaction is complete ; it is then run out into moulds.

The following are some of the results obtained :—

Description.	1.		2.	
	Before.	After.	Before.	After.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Sulphur	0·18	0·04	0·10	0·10
Silicon	1·40	0·70	1·00	0·10
Sulphur removed		77·0		90·0

Flames of what appear to be sodium burst out from the top of the vessel ; and the slags contain some of the sulphur as soluble sulphides.

Ball and Wingham's Process.

These gentlemen, in treating molten sulphurous iron with cyanide of potassium, caustic carbonate of soda, sodium ferrocyanide of potassium, found the following results, taking the best result of each series :—

Description.	Metal Containing Sulphur.	Sulphur Removed.
	Per Cent.	Per Cent.
With cyanide of potassium	0·72	100
Carbonate of soda and cyanide mixed	0·46	87
Carbonate of soda alone	1·11	86
Carbonate of soda and caustic soda	0·26	92
Caustic soda alone	0·72	83
Sodium	0·18	100

VII.—THE HOERDE PROCESS.

This process having been so recently described before the Institute, it will not be necessary for me to more than briefly refer to it. Practically it consists in mixing together in a suitable "metal mixer," pig iron, poor in manganese and high in sulphur, with iron containing a larger percentage of manganese and little sulphur; the manganese of the one charge acting upon and combining with the sulphur of the second, the sulphur so formed separates from the metal and rises to the surface by gravity.

The fact that manganese, when added to metal containing sulphur, causes elimination of that element, was first noticed by Caron, who melted sulphurous iron with ferro-manganese (6 per cent.), and eliminated by that means 90 per cent. of sulphur. He also confirmed Parry's statement that manganese in the blast furnace caused the absence of sulphur in the pig iron.

Percy, discussing Caron's remarks on the effects of manganese on pig iron, says, "It would appear that the Mn acts as a medium through which the sulphur is oxidised and eliminated in the state of SO_2 ."

Caron, however, is of a different opinion, and concludes that, without any oxidising action, S disappears from cast iron in presence of Mn.

Ponsard states that 80 to 90 per cent. of S may be removed

from pig iron by stirring ferro-manganese into the ladle at the time of running. 2·6 of Mn removes 1 of S; the S is found in the slag.

Mr. Ed. Riley, in 1877, describes an experiment of his in which he melted cast iron containing 0·207 per cent. of sulphur with 10 per cent. of ferro-manganese in a crucible, and found that the sulphur was reduced to 0·037 per cent.; but I have failed to find any explanation as to the change or reaction which was effected.

Walrand melted sulphurous iron and spiegel in separate crucibles (the latter under lime), and poured the metal into the crucible containing spiegel, and, on stirring them together, sulphurous acid was evolved, and the mixture of metals caused a reduction of the sulphur from 0·50 to 0·06 per cent.

The accompanying diagrams were constructed from investigations made at the Hoerde Works by Herr Massenez, Mr. E. H. Cook, Mr C. H. Ridsdale, and myself:—

ANALYSES OF METALS BEFORE AND AFTER PASSING THE MIXER
AT HOERDE, MARCH 1892.

By Mr. E. H. COOK.

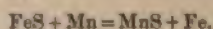
	Metal from Three Furnaces.			After Passing Through Mixer.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Iron	92·65	93·40	91·18	92·41
Combined carbon	3·00	2·80	3·05	3·05
Manganese	1·72	1·30	2·50	1·68
Silicon	0·46	0·20	0·80	0·69
Sulphur	0·15	0·20	0·08	0·04
Phosphorus	2·02	2·10	2·39	2·13
Total	100·00	100·00	100·00	100·00

Mixer Slag.

	Per Cent.
Silica	32·30
Iron	5·80
Manganese	33·46
Sulphur	5·75

The following experiment was made in my laboratory to

verify the statement of Herr Massenez. One hundred parts of ferro-manganese and a quantity of sulphide of iron, both in fine powder, were melted together in a plumbago crucible. After fusion and cooling, the crucible was broken and the contents were examined. On the surface of the metal, scoria was found containing 56 per cent. of manganese, 28 per cent. of sulphur, and 1 per cent. of iron. The metal contained only 0.02 per cent. of sulphur, which demonstrated most conclusively that the reaction had been according to the following equation:—



Ordinary foundry iron containing manganese, after melting in a cupola, and pouring into large moulds, in which it remains for a considerable time in a fluid condition, is liable to have a concentration of sulphide of manganese near the highest or most elevated part of the casting. This fact was, I believe, first noticed by my former assistant, Mr. Harold Ridsdale, who sent me the following analyses of the upper and lower part of a large ingot mould, viz.:—

	Upper Part.	Lower Part.
Sulphur	0.75 per cent.	0.112 per cent.
Manganese . . .	1.35 "	0.547 "

Strange to say, this large quantity of sulphur and manganese did not cause the metal to be white, from which it may be assumed that when the manganese and sulphur dissolved in metal are combined together, they do not exert the same influence in preventing the carbon assuming the graphitic condition as when in combination with the iron.

VIII.—SANITER'S PROCESS.

Essentially this process of desulphurising metal or steel in the basic open hearth, consists in the use of about $\frac{1}{2}$ cwt. of crude calcium chloride per ton of steel (which is added to the furnace when the charge is melted), in conjunction with an excess of lime over and above what is usually employed.

So far as the working of the charges is concerned in other respects, there is no deviation from ordinary practice.

The amount of limestone added with the pig and scrap is greater than in ordinary work, and as soon as the whole of the

ired amount of calcium chloride is added to the melted
ge, lime and mine are thrown in as required, in the
l way.

n February 9 of this year I visited the Wigan Steel Works,
was present during the working of several charges of iron
ted by this process, and obtained the following result on
ysis, viz. :—

MATERIAL USED IN THE FURNACE.

Pottery Mine.

	Per Cent.
Peroxide of iron	71.80
Protexide of iron	9.70
Phosphoric acid	1.50
Siliceous matter	4.00
Sulphur	0.30

Lime.

	Per Cent.
Lime	93.00
Magnesia	1.05
Alumina	0.55
Peroxide of iron	trace
Silica	1.25
Sulphuric acid	0.10
Loss by calcination	4.05
Total	100.00

Calcium Chloride.

	Per Cent.
Calcium chloride (by difference)	70.27
Magnesium chloride	0.18
Silica and oxide of iron	0.11
Sulphate of lime	trace
Water	29.44
Total	100.00

	Calculated Analysis of the Charge.	7.20 After Melting.	8.35 After Adding CaCl ₂ .	10.10	11.30	Steel.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
on	1.67	0.40	0.33	0.22	0.15	0.15
p	0.15	Trace	...	...	...	Trace
ur	0.37	0.36	0.093	0.082	0.058	0.047
horus	1.67	1.25	1.106	0.340	0.065	0.058
anese	0.46	0.22	...	...	...	0.390

Slags.

	7.20 Before adding CaCl ₂ .	After Adding CaCl ₂ .	Steel Slag.
	Per Cent.	Per Cent.	Per Cent.
Lime	58.50	54.65	48.98
Chloride of calcium	7.70	1.02
Iron	2.20	10.20
Protoxide of manganese	2.80	5.01
Silica	10.75	10.20
Phosphoric acid	10.81	12.30
Sulphur	1.25	0.65

Sulphur removed in $1\frac{1}{2}$ hours after adding chloride of calcium = 73 per cent.

Total sulphur removed = 87 „

On August 9, 1892, I watched a charge of metal worked at the Wigan Works, and the following are the analyses of the products:—

FURNACE D, 1121, August 9, 1892.

	From Charge after Melting.	One Hour after Adding Calcium Chloride.	Slag at the Time of Tapping.
	Per Cent.	Per Cent.	Per Cent.
Lime	42.42	44.34	47.86
Calcium chloride	Trace	6.65	1.66
Magnesia	5.11	4.61	4.03
Protoxide of manganese	7.18	3.20	3.37
Peroxide of iron	2.43	2.28	4.57
Protoxide of iron	4.63	3.34	10.41
Alumina	2.24	1.65	1.78
Silica	19.45	14.45	11.75
Sulphur	0.28	0.53	0.57
Phosphoric acid	15.34	18.60	13.73
Not determined	1.02	0.81	.55
Total	100.14	100.26	100.28
Less oxygen of lime combined with S	0.14	0.26	0.28
Total	100.00	100.00	100.00

<i>Metals.</i>			
Carbon	0.83	0.34	0.120
Manganese . . . . .	...	...	0.650
Silicon	Trace	Nil	Nil
Sulphur	0.17	0.082	0.055
Phosphorus	1.07	0.65	0.048

Sulphur removed one hour after adding chloride of calcium = 52 per cent.

Total amount of sulphur removed = 67 „

The lime is evidently deficient in this charge, which may account for the less perfect elimination of sulphur.

Removal of Sulphur from Fluid Cast Iron.

This process is similar to those of Heaton and Warner, but instead of using alkaline salts, a mixture of lime and chloride of calcium is employed. With Mr. Saniter's consent, I saw a charge of iron treated on the 9th of August, and I analysed the metal before and after passing through the purifying process.

As the metal at the furnaces at the time of my visit was of a rich character, and almost free from sulphur, I was informed that it was not suitable for desulphurising; but I pointed out that in all purification processes it is the last traces which are most difficult to remove, and that if sulphur was removed in any amount whatever from iron containing less than 0.05 per cent. sulphur, we should have confidence in believing that a greater proportion would be removed from more sulphurous material. It was, therefore, arranged to make a trial with the iron just as it was.

For this purpose about 70 lbs. of crude chloride of calcium, containing

Description.	Dried.	As Received, Crude.
	Per Cent.	Per Cent.
Calcium chloride	97.60	70.27
Magnesium chloride . . .	0.25	0.18
Insoluble residue	0.15	0.11
Sulphate of lime	trace	trace
Water	2.00	29.44
	100.00	100.00

was mixed in powdered state with 60 lbs. of crushed lime, and the mixture was placed on the bottom of an ordinary ladle lined with fire-bricks. The ladle was heated before the mixture was added.

Some pieces of wood were thrown on the surface of the mixture to prevent the stream of metal which was afterwards poured into

the ladle from passing under and through it. This I was informed was not usually done.

When the blast furnace was tapped the first portion of metal run was directed into the ladle, which it nearly filled ($2\frac{1}{2}$ tons).

As soon as the metal passed into the ladle, flames and fumes were copiously given off. The flames were no doubt due to a certain extent to the effect of the heat on the wood ; but the water added in the chloride of calcium must have been decomposed, and the hydrogen liberated, which of course burnt at the top of the metal. Fumes of hydrochloric acid were also detected. The action seemed to be very energetic, and only lasted for about three minutes.

The slag on the surface, and the metal below were both quite fluid, and the latter, as soon as the reaction had ended, was poured into moulds on the pig bed.

No skull was left in the ladle, and apparently the "mixture" had very little chilling effect on the metal.

The metal before and after treatment was sampled, and analyses made in my laboratory, with the following result :—

	Metal Before Treatment. Per Cent.	Metal After Treatment. Per Cent.
Sulphur	0.036	0.012
Manganese	above 2 per cent.	
Sulphur removed		66 per cent.

It is unfortunate that the sulphur was not higher, and the manganese less, as it is impossible to say in this experiment whether the desulphurisation was effected by the manganese or the "mixture." Mr. Saniter informs me, however (and I have no reason to think differently), that on an average above 70 per cent. of the sulphur is removed, even when manganese is absent.

It is worthy of note that in the slags containing calcium chloride and lime, there is little or no tendency for sulphur, when present, to pass into the steel, and that in consequence ores such as purple ores (containing a considerable quantity of sulphur), can be used in the open-hearth process without danger. In other words, the slag may be highly charged with sulphur without any of it escaping into the steel.

Thus the analysis of the slag from the first charge examined by me at Wigan, when it was treated by Saniter's process, shortly after adding the chloride of calcium, showed 1.25 per cent. of sulphur.

Judging from the fact that by this process above 70 per cent. of sulphur can be removed from the charge of metal in an open-hearth furnace, and from liquid metal at a comparatively small cost, it appears to me it is a valuable discovery, and likely to be of great use to the iron and steel manufactures.

The following experiments were made to ascertain the nature of the chemical changes which occur during desulphurisation in this process.

Sulphurous Iron heated on Carbon under a Mixture of $\text{CaCl}_2 + \text{CaO}$.

Five grams heated in a brasqued crucible for one hour to whiteness yielded metal containing:—

	Before. Per Cent.	After. Per Cent.	Eliminated. Per Cent.
Sulphur . . .	0.41	0.011	97

Sulphurous Iron heated in a Lime-lined Crucible, under a Mixture of $\text{CaCl}_2 + \text{CaO}$.

Five grams were simply melted under an excess of calcium chloride and lime.

	Before. Per Cent.	After.	Eliminated. Per Cent.
Sulphur . . .	0.41	trace.	100

The sulphur was in the slag.

Sulphurous Iron washed with a Mixture of 80 per cent. CaCl_2 and 20 per cent. CaO .

One hundred grams of very sulphurous metal was poured into a plumbago crucible containing an excess of molten oxychloride (free from sulphur), and the contents were gently shaken together for one minute, after which they were poured into a mould.

	Before. Per Cent.	After. Per Cent.	Eliminated. Per Cent.
Sulphur . . .	1.86	0.04	98

The slag contained 1.02 per cent. sulphur.

Iron heated with Calcium Chloride.

I have heated iron drillings to bright redness under fused chloride of calcium in a platinum capsule for different periods of time, and have observed that the iron remains quite bright at first, and that flakes of specular oxide of iron are formed in the liquid chloride, but that, as the heat is prolonged, a coating of oxide is formed on the surface of the iron.

This experiment proves that, when exposed to the air, chloride of calcium has a distinct action on iron when they are both at such a temperature as will keep the chloride perfectly fluid, the iron being well below the surface and not exposed to direct oxidation.

The presence of flakes of specular oxide would favour the theory that chloride of iron is formed, and its vapour afterwards decomposed by the lime of the chloride.

The oxidising action on iron is greatly accelerated if a small proportion of lime is mixed with the chloride. In such a mixture the iron is rapidly coated with a layer of oxide of iron.

Chloride of Calcium heated in contact with air.

When chloride of calcium is heated in contact with air containing moisture, free hydrochloric acid and lime are produced. The following results show the composition of the chloride, before and after heating for one hour in an open platinum capsule freely exposed to moist air:—

	Pure Chloride. Per Cent.	After Heating for One Hour. Per Cent.
Calcium chloride	100·00	85·61
Calcium oxide (lime)		14·39
	<hr/> 100·00	<hr/> 100·00

The mixture above mentioned, containing 14 per cent. lime, was, when heated, quite fluid and transparent, proving that the compound consisted either of chloride of calcium with lime in solution, or an oxychloride of calcium.

Calcium Chloride melted with Sulphur.

Calcium chloride melted in a plumbago crucible with an excess of roll sulphur only absorbed 0·219 per cent., indicating that practically it is incapable of absorbing sulphur *per se*.

Sulphide of Iron melted with Calcium Chloride.

When equal weights of these substances were melted together, the sulphide separated, but the chloride retained 0.429 per cent. of sulphur, and 2.9 per cent. of iron.

Sulphide of Iron melted with Lime and Calcium Chloride.

Sulphide of iron melts readily, and dissolves in oxychloride of calcium, into an apparently homogeneous mass, from which there seems to be no tendency for sulphide of iron to separate.

From the experiments referred to in speaking of the behaviour of sulphur in the blast furnace, it has been shown that lime and sulphide of iron, on heating, change to oxide of iron and sulphide of calcium. The compound above described may therefore be considered as calcium chloride, with those bodies in solution.

Sulphurous Iron melted with Calcium Chloride alone.

On keeping these bodies together in a molten condition for half an hour, the metal lost 31 per cent. of its sulphur, being reduced from 0.40 per cent. to 0.274 per cent.

Calcium chloride loses chlorine on heating in air, lime and hydrochloric acid being formed; it is possible, therefore, that in the last experiment the free lime was responsible for what sulphur was removed from the iron.

Sulphurous Iron heated with Lime and Charcoal.

Five grams of iron were placed on the bottom of a brasqued crucible, and covered with five grams of lime. The mixture was exposed to a white heat for one hour. The iron before and after treatment had the following composition:—

	Before. Per Cent.	After. Per Cent.	Eliminated. Per Cent.
Carbon . . .	2.04	...	...
Silicon . . .	0.14	...	...
Sulphur . . .	0.40	0.025	94
Phosphorus . .	2.14	...	...
Manganese . .	0.45	...	...

Sulphur was found in the adhering lime.

Sulphurous Iron heated with Lime alone.

Five grams were placed on the bottom of a lime-lined crucible, and were covered with lime. This was heated to whiteness for two hours. The metal contained, before and after treatment:—

	Before. Per Cent.	After. Per Cent.	Eliminated. Per Cent.
Carbon	2.04	0.35	...
Sulphur	0.40	trace	100

The lime contained sulphide of calcium.

This experiment clearly proves that lime alone is capable of removing sulphur from iron; it seems probable, therefore, that if liquid iron was to be agitated, with solid lime, at a temperature above the melting-point of the iron, so that fresh surfaces of lime and iron should be continually exposed to each other, a more rapid elimination would obtain. To ascertain if this was the case, a large plumbago crucible, six inches in depth, was filled with pieces of lime between $\frac{1}{4}$ -inch and $\frac{1}{2}$ -inch in diameter. This was placed in a furnace and heated above the fusion-point of cast iron; a small quantity of fluid iron was poured into it, and after shaking the crucible for five minutes (to allow the metal to trickle to the bottom), the fluid iron was poured out and afterwards analysed, and was found to contain—

	Before.		After.
Sulphur, 0.51 per cent.			0.27 per cent.
„ removed	=		47 „

These results would lead us to believe that if a tower or column of lime sufficiently tall could be maintained at a sufficiently elevated temperature, the whole of the sulphur would be removed from a stream of sulphurous iron if it was allowed to simply gravitate through it.

It is not suggested that any practical attempt should be made in such a direction, for more simple and less expensive methods are available, but rather to indicate that, by subdividing a stream of metal, and exposing the largest possible surface of it to clean and non-saturated surfaces of solid lime, sulphur would probably be more rapidly removed than is the case when a mass of metal is heated in contact with the same surfaces of lime.

How Lime removes Sulphur from Cast Iron.

In the reducing conditions of a blast furnace, it can readily be understood that the lime is reduced and made available to combine with sulphur, for carbon exists in large quantities, and carbonic oxide is predominant. The action of free lime without the accompanying conditions is not so clear, unless the metalloids present in the iron itself are the agents responsible for the reduction of the lime, for it must be remembered that in all cases where lime at high temperature has acted on sulphurous iron, the sulphur removed has been found in combination with calcium, and some agent must therefore have been at work to remove oxygen from the lime before it could combine with the sulphur. It would appear also that sulphate of lime could not possibly be formed, as it cannot exist in presence of iron at a high temperature. In the experiment given previously, in which sulphurous iron was heated with lime, it will be noticed that the carbon, as well as the sulphur, was removed, the carbon having been reduced from 2.04 per cent. to 0.35 per cent. This shows most clearly that more had been removed than was sufficient for the reduction of the lime to calcium required by the sulphur. Now this was rather puzzling. It was thought possible that this excessive oxidation might be caused either by some CO_2 in the lime used, or by oxidation by the gases from the furnace, which might have entered through the porous lime in the crucible. An experiment was arranged so as to avoid these objections. For this purpose a plumbago crucible was first lined with lamp-black, then three-parts filled with lime, mixed with benzole to enable it to be moulded into shape, and three small pockets formed in triangular position, after which the crucible with its contents was heated, at first gently, and afterwards at a white heat in air, so as to burn out the benzole and carbonic acid.

When cool, five grams of sulphurous white iron was placed in one pocket, five grams of grey iron, containing sulphur and manganese, in the second, and the same quantity of iron, free from sulphur and silicon, in the third. About one inch of lime was placed over these, and over the lime a second layer of lamp-black. A plumbago lid was then fixed on the crucible, which

was placed with its contents in a furnace, and there maintained for two hours at a white heat.

The metals were all fused, and adhered most closely to the lime, which had to be removed by acid before they could be tested.

During this cleaning process, sulphuretted hydrogen was evolved, as the lime adhering to those metals which originally contained sulphur passed into solution. The metals before and after this treatment had the following composition:—

	White Metal.		Grey Hematite.		Pure White Iron.	
	Before. Per Cent.	After. Per Cent.	Before. Per Cent.	After. Per Cent.	Before. Per Cent.	After. Per Cent.
Carbon . . .	2.04	1.30	3.40	1.75	3.91	1.75
Manganese . .	0.45	0.41	1.72	0.88	0.55	0.41
Silicon . . .	0.14	nil.	2.10	nil.	0.14	nil.
Sulphur . . .	0.40	trace	0.86	0.04	0.01	trace.

A second trial was made with the sulphurous grey and white iron, but in this case the drillings of the grey iron were mixed with the lime, so as to expose a large surface of the metal to the action of the base. The time of exposure was less for the grey iron than for the white. The metals, before and after treatment, had the following composition:—

	White Iron.		Grey Iron.	
	Before. Per Cent.	After. Per Cent.	Before. Per Cent.	After. Per Cent.
Carbon	2.04	0.66	3.40	3.20
Silicon	0.14	trace	2.10	0.13
Manganese . . .	0.45	...	1.72	2.01
Sulphur	0.40	0.03	0.86	0.14

Now, judging from these results, it would seem—First, that the metalloids in the iron, during their removal, may have effected the reduction of the calcium oxide, and the calcium have then combined with the sulphur; second, that some energetic oxidising influence or agency must have been at work, which was not influenced by the sulphur present; for not only were the carbon and silicon removed from the sulphurous irons, but a great part of these bodies was oxidised from the white iron which contained no sulphur.

When we consider that the lime was completely surrounded by an envelope of carbon, and that, owing to the porous character of the lime, carbonic oxide must have passed freely through the

mass, and the reaction have been in presence of that gas, and therefore in a strongly reducing atmosphere, it is amazing that such powerfully oxidising influences were at work as to remove so much silicon and carbon, the only substances present being pure lime and carbonic oxide. We know well enough that carbonic oxide is reduced by silicon, silicon and carbon resulting; and if this reaction took place, we should have expected that the carbon would have been present in increased proportion in the metal; but as this was not the case (that element being materially reduced), we are at present at a loss to account for the cause of the oxidation, unless we assume that the lime itself is responsible in some way for the oxidation.

Another remarkable feature in these trials is that, contrary to all previous experience as to the relative oxidation of silicon, manganese, and carbon, in the latter trial the manganese appears to have been but slightly affected, whilst the silicon is completely removed. It would appear that, under the conditions of these experiments, silicon is almost completely eliminated before the manganese is oxidised.

These results certainly open a large field for research, which we must follow up before a true explanation can be given of the chemical reactions involved.

Now, judging from the fact that chloride of calcium alone has little power in removing sulphur, it appeared probable that its elimination was mainly due to the effect of the lime dissolved in it, and that if this was so, sulphur would be eliminated in all cases if a liquid agent, containing free lime, or lime loosely attached in such liquid, was brought into contact and agitated with molten iron.

In order to check this theory, sulphurous iron was melted in contact with the fusible compounds of lime and calcium chloride, fluor spar, boracic acid, and magnetic oxide of iron, respectively, all of which dissolve or combine with an excess of lime. Chloride of calcium stands pre-eminently in the first place as a solvent of lime, fluoride of calcium comes perhaps second, borate of calcium third, magnetic oxide perhaps next, last of all silicate of lime. Silicate of lime is capable of combining with a considerable excess of lime, but it is perhaps open to question whether

exceedingly basic furnace slags do contain the lime in solution, or feebly chemically attached to the silica. It has, however, been conclusively demonstrated that such calcareous slags do remove sulphur from iron, and that lime, whether in solution or combined in them, is readily available.

The result of simply melting together iron containing sulphur and the above-mentioned calcareous compounds was as follows:—

	Before. Per Cent.	After. Per Cent.	Eliminated. Per Cent.
Cast iron with $\text{CaC}_2 + \text{CaO}$	0.40	trace	100
" with $\text{CaF}_2 + \text{CaO}$	0.40	0.027	93
" with $\text{Ba}_3\text{O}_4 + \text{CaO}$	0.40	0.081	80
" with $\text{Fe}_4\text{O}_3 + \text{CaO}$	0.40	0.030	92

The last compound contained 17 per cent. iron as oxide. All of these results point to the conclusion that lime is the acting agent, and that the calcium chlorides and other compounds are only indirectly responsible, being, in fact, vehicles by which the lime is brought into intimate contact, physical and chemical, with the sulphurous iron.

We see then that solid lime alone will desulphurise iron more or less rapidly, the rate depending on the degree to which fresh surfaces of lime and molten iron can be brought into actual physical contact; also, that lime, with any substances capable of dissolving it at a temperature above the melting-point of the iron operated upon, must necessarily and actually does come into a much closer physical contact with the molecules of the crude iron in a given unit of time, and therefore must necessarily effect a proportionately more rapid desulphurising action.

Many years ago, when investigating the efficiency of Mr. R. Howson's rotary blow-pipe puddling furnace, it was observed that when the temperature was insufficient to melt the fettling used to line the furnace, the dephosphorisation was most inefficient, but when the heat was raised, and the fettling melted, much more phosphorus was removed. In the first instance, the fluid iron was in contact with a powerful dephosphorising agent in a solid state, which effected little or no removal of phosphorus, whereas as soon as the agent was liquified a very different result followed.

In experiments made in my laboratory many years ago, in which Cleveland iron was agitated with fluid basic silicates of iron, it was noticed that when the cinder was not fully liquid the amount of phosphorus removed was not nearly so great as when greater fluidity was obtained.

Now, it appears to me that there is a close analogy between the action of solid and fluid oxide of iron in the dephosphorising processes and the solid lime and fusible lime compounds in the desulphurisation processes, and that the conclusions above stated are in all probability very near the truth.

The fact that no sulphur was removed in the first trial I made at Wigan with a slag containing 58 per cent. lime, rather tends to upset this theory. It must, however, be noted that this slag was very thick and pasty.

The use of calcium chloride enables us to demonstrate most clearly what has been before set forth, viz., that provided lime can be brought into such contact, and in more than sufficient quantity, as to combine with all the silica and sulphur (even although a very large amount of sulphur is contained in the material), when it is smelted at the very lowest temperature at which cast iron will form, it will contain little or no sulphur. The following experiment proves this to be the case:—A portion of the compounds used in previous experiments, consisting of oxides of iron and calcium sulphide, and containing 12 per cent. of sulphur, was mixed with an equal weight of calcium chloride and charcoal, and this was smelted at a moderately low temperature in a plumbago crucible. A white iron was produced, which contained only a *trace of sulphur*, and no silicon.

In concluding this paper, I must express regret that we still are far from having a perfect knowledge of the subject. There is much work yet to be done.

I must also ask you not to accept as laws the theories and deductions I have advanced, unless you yourselves feel justified (judging from a consideration of all the facts and conditions) in so doing; always keeping in mind that they are based on such truths as we have been able to obtain, and that further investigation may give us much more information, and cause us to considerably modify our views.

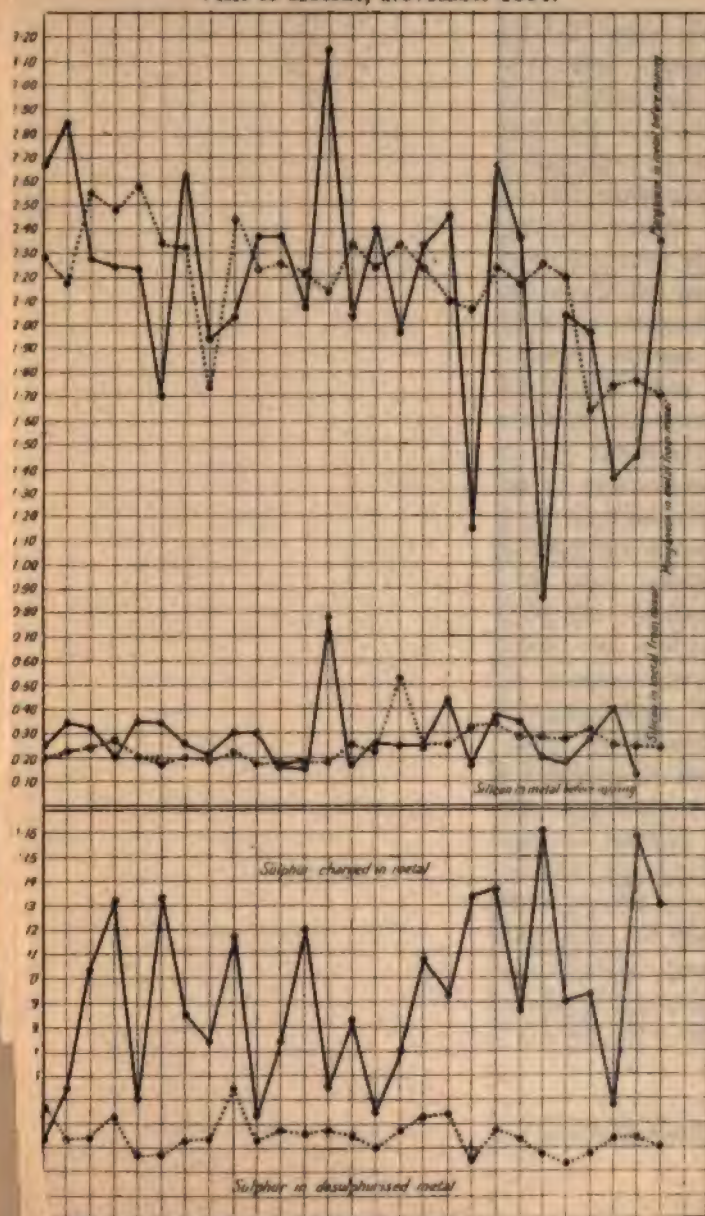
The result of careful experiment is the voice of Nature speaking truth. The interpretation of it is the work of fallible humanity.

We all must regret that the past progress has been in great measure prevented in consequence of incorrect deductions and prematurely formed theories.

Note.—The foregoing paper was presented to the meeting in two instalments, only one of which was printed in advance. This explains the references to "two papers" in the discussion which followed.—Ed.

Massenez's Process.

Investigations of J. E. STEAD and C. H. RIDSDALE during a
Visit to Hoerde, November 1891.





DISCUSSION.

The PRESIDENT said that Mr. Stead had landed them in a great difficulty. He had first of all given them a paper, of the merits of which, from a previous perusal, they had formed a very high opinion, and the substance of which they were prepared to discuss; but then he had supplemented this paper by another—he would not say quite so long, but certainly containing at least as important, and probably more important, matter than the original paper itself. They had only about a quarter of an hour left for the discussion of these two very important papers, and of Mr. Saniter's communication, and under the circumstances he thought the only course open to them was to adjourn this discussion until the May meeting. They would then have an opportunity of carefully considering the further important results which Mr. Stead had laid before them, and Mr. Stead and Mr. Saniter would also have an opportunity of communicating accounts of further work in this direction as supplements to their present papers; at any rate, they would have the benefit of the subject being thoroughly dealt with by those gentlemen, as well as of its being carefully considered by the members of the Institute. The subject was a very important one, and one which could not be dealt with lightly, and he therefore proposed the adjournment of the discussion. At the same time, by way of commencing the discussion, he would invite Sir Lowthian Bell to make a few remarks, especially with reference to Mr. Stead's paper. Of Mr. Saniter's paper, and the important results it brought before them, there could be but one opinion. It was a paper eminently worthy of very serious consideration by practical men, and so far as the practical results went, which he had detailed, they appeared to be confirmed by Mr. Stead's personal observations. But they could hardly discuss Mr. Saniter's process without considering the other important matters which, in connection with the general subject, Mr. Stead had brought before them.

SIR LOWTHIAN BELL said he generally agreed with the President,

but upon that occasion it seemed difficult to say where he should commence the discussion of the two papers. At some risk, however, he would say a few words upon what had been advanced by Mr. Saniter, rather than go into the labyrinth of figures and facts that had just been laid before them by Mr. Stead. He observed that Mr. Saniter stated (page 217)—“Should it be desirable to remove silicon, as well as sulphur, the lime of the mixture is replaced by hydrate or carbonate of lime, or even oxide of iron in addition, should these first be insufficient.” Now, there was, apparently, a very unimportant rôle assigned to the presence of oxide of iron. Before any great elimination of silicon could take place, he believed that the presence of oxide of iron was essential. They had in the iron, not silica, but silicon. Until they had oxidised the silicon in order to get silica, he did not see how it was possible to expect any reaction to take place such as Mr. Saniter mentioned.

Mr. Saniter would pardon him if he rather dissented from one of his statements as to the whole of the plant he required being of a simple and inexpensive character, consisting of ladles, or receivers on wheels. Of course, time was always an important element, for if they could not economise time, they probably could not economise money. He had made many experiments in the direction described by Mr. Saniter, and he had come to the conclusion that unless they had very efficient, and he might say, at the same time, rather expensive apparatus, they probably might find more difficulty in carrying on the operation with commercial success than was apprehended. At the Clarence Works they had recently erected, at considerable expense, an apparatus for clearing pig iron of its associated metalloids. That apparatus was now in operation, and so far it appeared to be very effectual for accomplishing the end for which it was intended. Beginning with something like $1\frac{1}{2}$ to 2 per cent. of silicon, they had on some occasions reduced it to something like .2 per cent. in about ten minutes. The reason he mentioned the subject was that if Mr. Saniter would like to have an opportunity of trying his process under favourable circumstances, he would be most happy to allow him the use of the apparatus.

He should like to have the opportunity of studying very carefully what Mr. Stead had brought before the Institute, and

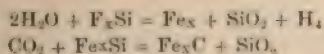
until he had done this, he would defer any remarks he might have to make.

With regard to the removal of sulphur from tank waste, mentioned by Mr. Stead, by fusing oxide of iron, an addition of some earth capable of rendering the silicate of lime fusible was, of course, needed, and as a matter of cost none was better adapted for the purpose than alumina, added in the form of old and useless fragments of brick.

Mr. SNELUS, in seconding the adjournment of the discussion, said he was quite sure that that would be the best course for the Institute to adopt, because it would give time and opportunity to the members to study the abstruse question brought before them and to read carefully Mr. Stead's paper, especially the supplementary one, which seemed to contain quite as much valuable information as the original paper.

The motion for adjournment was unanimously agreed to.

Mr. SANITER, in reply to Sir Lowthian Bell's remarks, would say that, at the temperature of molten iron both water and carbonic acid desiliconise iron, according to the following reactions:—



The time occupied in the operation does not exceed twenty minutes in the simple apparatus which is necessary.

Where ladles are already in use for conveying metal from the blast furnace to the steel-works, these ladles are sufficient to carry out the process; where this is not the case, and the metal has to be cast into pigs, plant of a similar description would be used, which would not, at the outside, cost more than £250 for a blast furnace. Mr. Saniter had to thank Sir Lowthian Bell for his offer to allow him to try his process at Clarence, which offer he should be glad to take advantage of at his convenience.

APPENDIX.

(Copy.)

BRUNSWICK WORKS, WEDNESBURY, *September 19, 1892.*

E. H. SANITER, Esq.

DEAR SIR,—I have pleasure in handing you the under-mentioned analyses of the working of two charges of high sulphur iron in our open-hearth basic furnaces.

Analyses of Pig Iron (67·3 per Cent. of Charges):—

	Per Cent.
Sulphur	·24
Silicon	·34
Phosphorus	2·76
Manganese	·65

Analyses of Steel made:—

	C.	SL.	S.	P.	Mn.
No. 1 charge	·09	trace	·047	·007	·56
No. 2 charge	·12	trace	·037	·013	·54

We experienced no difficulty in working, and the quality and yield of metal are good.—Yours faithfully,

GEO. A. MILLWARD.

VOTES OF THANKS.

The PRESIDENT said there was one other pleasing duty which the members had to perform before concluding their proceedings, namely, that of returning a cordial vote of thanks to Mr. Saniter and Mr. Stead for their valuable papers. It was now his duty to close the business portion of the meeting by moving the following resolutions, which he was quite sure would be in accordance with the wishes of the members:—

“ That the most cordial thanks of the Iron and Steel Institute be offered to the chairman, vice-chairman, secretary, and members of the Local Reception Committee for the complete and thoroughly satisfactory arrangements made by them for the present meeting; to the Mayor and Corporation of Liverpool for

placing at the disposal of the Institute the use of St. George's Hall; to the London and North-Western and Lancashire and Yorkshire Railway companies for the special train facilities accorded for the several excursions; to the engineers, contractors, and owners of the Overhead Railway, and to the owners of steamships, works, and other establishments thrown open to the members during the week, as well as to the Mayor of Chester, and to the Dukes of Westminster and Sutherland, for their co-operation in promoting the success of the present meeting."

Sir LOWTHIAN BELL, in seconding the motion, said he did not know whether the meeting was aware that it had been thought desirable on the present occasion to make a radical change in what he might call the economic side of their visits. He was quite sure, however, that no one would for a moment imagine that there had been any want of facility in carrying out the objects of their visit by the fact that the Council had declined to impose on their hosts such a lavish expenditure as had attended previous meetings. He therefore joined heartily with the President in seconding the motion.

The motion was unanimously adopted.

Sir JAMES KITSON, M.P., proposed "That the best thanks of the members of the Iron and Steel Institute be, and are hereby, tendered to Sir Frederick Abel, K.C.B., &c., for the successful manner in which he has, as chairman, conducted the proceedings of the present Autumn meeting of the Institute." It might be known to some of the members that some anxiety had been felt as to the place of meeting, and there had been some little discussion as to who should be their hosts. They had been fortunate in receiving an invitation from the authorities in Liverpool, and they had the satisfaction of knowing that they had not been a burden upon the gentlemen of the trade in the district. They had sometimes felt that the hospitalities which had been offered in many districts had been rather a tax, but they had now entered upon a new era, and they had just concluded one of the most successful meetings of the Institute. They now knew that they could pass from district to district on the present system with great advantage to the Institute. Their only object

as practical men was to obtain from their scientific friends all the information that could possibly be communicated by exposition and by the examination of works. They had been fortunate in their President, who, from his scientific position, had, during the period of his office, given an ultra scientific turn to the papers which had been brought before them, and to the discussions thereon. No more valuable papers, he thought, had been offered to the members than they had received during the past year.

He need scarcely refer to the very successful dinner at which the members had been assembled, or to the very genial way in which the President had conducted those difficult proceedings. He said "difficult," because sometimes Presidents were tempted to hold forth at great length, and Sir Frederick Abel had shown them an example of brevity, as well as of geniality, which he thought would be followed by other Presidents. They were greatly indebted to him for the manner in which he had conducted, not only the proceedings of the present meeting, but the proceedings of the Institute, and he was sure they would all cordially agree with him that Sir Frederick Abel was entitled to a hearty vote of thanks.

Mr. WILLIAM WHITWELL said that he rose with no ordinary pleasure to second the proposal so aptly and eloquently made by Sir James Kitson. He thought they might congratulate themselves on the present successful meeting. They could only regret that, according to the ordinary course of things, that was perhaps the last occasion on which Sir Frederick Abel would preside over them for the discussion of papers. He would, no doubt, open the meeting on the next occasion, when the new President was formally installed, but that was the last opportunity they would have of sitting under him as they had been doing during the last two years. He could endorse every word that had fallen from Sir James Kitson, in congratulating the members on the President of the Institute. He might perhaps also be allowed to congratulate them upon the excellent attendance that had characterised the present interesting meeting. He thought they had never had a meeting where the members had remained, and been interested to the last, as they had on the

present occasion. He not only congratulated them on having such a President and such an attendance, but he heartily congratulated the President on having the confidence and admiration of their ever-increasing number of members.

The motion was unanimously adopted.

The PRESIDENT said he felt overwhelmed by the kind expressions of the mover and seconder of the resolution. He had no doubt that any one in his position would have felt, as he did, that it was his duty to do his best for the Institute, in the prosperity of which they all took so great an interest. The calls upon the President were not perhaps very severe, but they nevertheless involved some attention, and some little use of the brain. If, in addition, a man exercised a small amount of tact, he would make a good President of the Iron and Steel Institute. He thought they might look forward to a continued prosperous career for the Society, and he trusted that many of those whom he saw present would hereafter fill, at least as moderately well as he had done, the office of President of the Institute. He would not detain the members any longer, but would only cordially echo the expressions of Sir Lowthian Bell, Sir James Kitson, and Mr. Whitwell in regard to the success of the meeting, and also with regard to the success of the new policy in reference to the Autumn meetings which had been inaugurated. He believed that the country meetings would in future be not less successful because they had somewhat altered their tactics, and, he might add, because they had asserted their independence.

APPENDIX.

VISITS AND EXCURSIONS.

TUESDAY, SEPTEMBER 20TH.

Two special excursions were arranged for the afternoon of this day—the first to the Horwich Locomotive Works of the Lancashire and Yorkshire Railway Co., and the second to the works of the Liverpool Overhead Railway.

A party of over a hundred members took advantage of the special free train kindly placed at their disposal by the directors of the Lancashire and Yorkshire Railway Co. to visit their well-known works at Horwich. The party was received and shown over the works by Mr. J. A. F. Aspinall, chief mechanical engineer. The works at Horwich were laid out in the year 1886, for the purpose of repairing and renewing the rolling stock, and executing such other engineering operations as are required from time to time. The workshops cover an area of about 15 acres in all, but upwards of 80 acres have been enclosed for the purposes of the works, giving ample scope for such future extensions as may be called for. Locomotives of the Company's standard type are not constructed here, but the works produce locomotive boiler trolleys, and several descriptions of goods wagons, which are made of iron or steel throughout. A Siemens plant is one of the adjuncts of the establishment. The Lancashire and Yorkshire Railway Company had in 1891, 1127 locomotives, 2952 passenger vehicles, and 21,923 wagons for goods and mineral traffic.

After being hospitably entertained at luncheon at the Adelphi Hotel by Mr. J. W. Willans of Manchester, the contractor for the undertaking, the second party of members was conveyed in omnibuses to the

Overhead Railway Works, which were examined with interest as being the first railway of its kind constructed in the United Kingdom. The line is about 6 miles in length, and skirts the system of docks for practically the whole distance. There is a double line of rails of the ordinary gauge. Hobson's decking is a feature of the work which was examined with interest, it being employed throughout the whole railway as the bed on which the rails are laid. The swing bridge over the Stanley Dock entrance, and other structural features of the enterprise, were pointed out by Mr. J. H. Greathead, the engineer, and Mr. Willans, the contractor, who took general charge of the party. The paper read at the meeting by Mr. J. H. Greathead, joint-engineer of the line, describes and illustrates the railway.

In the course of the afternoon a number of works in Liverpool and its neighbourhood were thrown open for the inspection of members, including the Bankhill Engine Works of Messrs. John H. Wilson and Co., where steam winches and cranes, excavators, and concrete mixing machines were, among other engineering items, shown in course of construction; the works of the Liverpool United Gas Light Company at Linacre, which are capable of supplying nine million cubic feet of gas daily; the Fulton Engine Works of Messrs. David Rollo & Sons, where general engine, boiler, and ship repairs are undertaken; the soap works of Messrs. Lever Brothers, at Port Sunlight; the reservoirs and pumping stations of the Liverpool Corporation, and the works of the Liverpool Hydraulic Power Company in Athol Street, which include two sets of Elkington's triple compound condensing engines, each of 200 horse-power, and two accumulators, with rams 18 inches diameter, by 20 feet stroke, and loaded to a pressure of 750 lbs. per square inch, which are used to maintain the pressure.

ANNUAL DINNER.

In the evening, the Annual Dinner of the Institute took place at the Adelphi Hotel, the chair being occupied by Sir Frederick A. Abel, K.C.B., F.R.S., &c., President. The company present included Sir Lowthian Bell, Sir James Kitson, the Mayor of Liverpool, the Mayor of Bootle, the Mayor of Chester, Professor Roberts-Austen, C.B., F.R.S., Mr. Edw. P. Martin, Mr. James Riley, Mr. G. J. Snelus, F.R.S., Mr.

William Whitwell, Mr. Thos. Wrightson, M.P., Mr. Benjamin Hingley, M.P., Professor Hele-Shaw, &c. The toasts included the Queen and the Royal Family, the Iron and Steel Institute, Kindred Institutions, and the City and Commerce of Liverpool. About 160 members and friends were present.

WEDNESDAY, SEPTEMBER 21ST.

The principal excursion fixed for this afternoon was one to the works of the Manchester Ship Canal. The party, which numbered over two hundred, left the Prince's Landing Stage in the steamship *Manx Fairy*, under the charge of Mr. E. Leader Williams, the engineer to the canal, and proceeded by river and canal to Weaver Pool, which is as far as navigation could be undertaken. The party had not the chance of seeing over any considerable part of the canal, nor was the opportunity afforded of witnessing the most difficult part of the work, but the trip, nevertheless, allowed of a general idea being formed of the character of this important undertaking. The total length of the canal is about $35\frac{1}{2}$ miles, and the total fall of water-level is $60\frac{1}{2}$ ft., which is divided among four sets of locks. The canal is tidal from Eastham, where it enters the river Mersey, to Latchford Lock, a distance of 21 miles. The waterway will be wide enough to allow of two large vessels passing one another along its entire route. Opposite the river Weaver, ten large sluices, each 30 feet wide, have been built in the embankment of the canal, in order to allow of the water of that river passing out of the canal, and for the purposes of tidal flow. The embankments between Eastham and Runcorn, alongside which the party was carried, are 25 feet wide at the top, and in these three weirs were being constructed, each 600 feet long, in order to allow of the flow of the tide when it is above the ordinary water-level. The party returned to Liverpool before six o'clock, having seen as much of the undertaking as was possible under the circumstances.

In the course of the afternoon, a number of members visited the well-known works of Messrs. Laird Brothers, at Birkenhead, including the principal works in Church Street, and the boiler works in Beaufort Road, where they saw engineering and shipbuilding work in different stages of construction. The *Royal Oak* battleship, which Messrs.

Laird had under construction for the British navy, was examined with interest.

Other members visited the pumping, ventilating, and hydraulic machinery of the Mersey Tunnel Railway, at Hamilton Square Station, Birkenhead. The special features of this railway are the hydraulic lifts, of which there are six at different stations, each capable of carrying 100 people, and having about 87 ft. height of lift; the ventilating fans, five in number, which draw the foul air from the centre of the river tunnel through an independent heading, while fresh air enters at the stations to replace that sucked out by the fans; the forcing pumps on either side of the river, which work about five strokes per minute, and raise in that time 4000 gallons to a height of 170 ft.; and the locomotives, which are of specially powerful construction, and condense the whole of the exhaust steam while running in the tunnel. The steepest gradient worked is 1 in 27. The passenger vehicles are fitted with the automatic continuous vacuum brake, and are lighted by compressed gas on Pintsch's system, while the rails are of 86 lbs. per yard, and the chairs weigh 54 lbs. each.

The Phoenix Foundry of Messrs. Fawcett, Preston, & Co., in York Street, was open to members during the afternoon. These works are interesting, as being the oldest engineering works in Liverpool. They are engaged in the manufacture of machinery for sugar-mills, producing cane-crushing mills, multiple effect vacuum apparatus for evaporating water from the cane juice, machinery for the manufacture of nitrate of soda, &c. Presses of the cyclone type for pressing jute, cotton, &c., are constructed at the Phoenix Foundry, three of them, each weighing about 95 tons, having been constructed and shipped to India and China just before the date of the visit of the party.

In the evening, the members of the Institute were received at a *conversazione* in the Walker Art Galleries by the Mayor and Mayoress of Liverpool (Mr. and Mrs. James de Bels Adam). The gathering was large and fashionable, and the occasion was rendered interesting by the admirable collection of pictures which the Galleries contain.

THURSDAY, SEPTEMBER 22ND.

The programme of visits arranged for the afternoon of Thursday included a visit to the Engineering Laboratories of University College, Liverpool, and an inspection of the principal docks and warehouses. At the Laboratories, Professor Hele-Shaw had got together a number of interesting models, which were inspected with interest, as well as an American chain-making machine, which was seen in operation, producing chains from steel wire at the rate of about a mile a day, with only one attendant. The tests made of this chain show it to possess a higher strength, weight for weight, than chain made in the ordinary way.

A considerable party devoted the afternoon to an inspection of the Liverpool Docks and Warehouses, under the guidance of Mr. A. G. Lister, Assistant Engineer to the Dock Board. The principal features of interest examined in the course of the drive were the tanks where the petroleum is stored at the Herculaneum Docks, the Coburg Pumping Station, the Canada Branch Dock, and the Langton Graving Docks. The members saw several new docks of large dimensions in course of construction. At the Alexandra Dock, where the trip ended, the party had the opportunity of seeing over the Cunard steamship *Umbria*, while some others visited the Inman Line steamer the *City of New York*, on the other side of the river.

The Pemberton Collieries of Messrs. J. Blundell & Sons, near Wigan, and the Chemical Works at St. Helen's, were available for inspection during the afternoon.

FRIDAY, SEPTEMBER 23RD.

Arrangements were made to afford members the opportunity of seeing on this, the last day of the meetings—

- (1.) Chester and Eaton Hall.
- (2.) Stoke-upon-Trent and Trentham Hall; and
- (3.) Lake Vyrnwy, in North Wales.

The larger number preferred to visit Chester, where a party of over a hundred was most hospitably entertained at luncheon in the Town Hall, by the Mayor of Chester—Charles Brown, Esq.—who similarly entertained the Institute on the occasion of the Chester meeting in 1884. The works of the Hydraulic Engineering Company at Chester, and of the Dee Iron Company, and Lloyd's

Cambrian Chain and Anchor public testing works, at Satney, were open for inspection during the day. Eaton Hall was visited in the course of the afternoon. His Grace the Duke of Westminster received the party, and showed them first over the stables, where the principal horses were trotted out, and afterwards over the Hall, where refreshments were hospitably provided. On the proposal of Mr. Alderman Bantock, of Wolverhampton, a cordial vote of thanks was given to His Grace for his kind attention and courtesy. In acknowledging the vote of thanks, His Grace regretted that the time was so short as to have compelled a somewhat hurried visit, but he hoped that more time would be available next time the Institute visited Chester.

The party that proceeded to Stoke-upon-Trent, in order to visit the works of Messrs. R. Heath & Sons at Ford Green, the principal potteries in the district, and the seat of His Grace the Duke of Sutherland, numbered about seventy. At Ford Green they were shown over the Norton works of Messrs. R. Heath & Sons, and saw the special plant provided there for the condensation of ammonia. Two furnaces were in blast, each producing about 220 tons of pig iron per week, with a total consumption of some 780 tons of coal. The make of sulphate of ammonia with the two furnaces was stated to be about 5 tons per week, while 24 tons of pitch, and 11 tons of oil, are also obtained.

On returning from Ford Green to Stoke, the members were entertained at lunch at the Railway Hotel by Messrs. Heath & Sons, the chair being taken by Mr. Robert Heath, jun., who undertook the arrangements generally, and carried them out with much thoughtfulness. In consequence of the decease of the Duke of Sutherland, Trentham Hall was not visited, but six of the principal potteries in Stoke were open for inspection during the afternoon, including the works of Messrs. Minton, Messrs. W. T. Copeland & Co., and Messrs. T. C. Brown-Westhead, Moore, & Co.

The third and final excursion of the meeting was taken by a limited number of members to Lake Vyrnwy—the new source of the water-supply of Liverpool, near Llanfyllin, North Wales. This party was under the guidance of Mr. Deacon, the engineer to the Liverpool Corporation.

A numerous and influential committee was constituted in Liverpool for the reception of the Institute, of which the Mayor (Mr. James de Bels Adam) was chairman, the Mayor of Bootle was vice-chairman, and Mr. R. C. F. Annett was secretary.

OBITUARY.

WILLIAM RICHARDSON was born at Horbury, near Wakefield, on the 11th of August 1811, and, in the year following, his parents went to reside at Cooper Bridge, near Huddersfield, his father having obtained an appointment under the Calder and Hebble Navigation Company. Born with a strong and vigorous constitution, the son, at an early age, was sent to the village school, where he remained until he was eight years old, when he was set to work to assist in the domestic hand loom weaving industry. When eleven years of age, he entered the cotton mill of Mr. Thomas Haigh, Colne Bridge, where he found suitable employment in connection with the various machines used for the preparing and spinning of cotton. In 1823 he was bound apprentice, entering the mechanic's shop connected with the mill, and he remained there until 1833, having during this period diligently applied himself to remedy the defects of his scanty education, and to make himself practically acquainted with every machine in the mill, as well as with the water-wheel and its connections, by which the machinery of the mill was driven. On leaving Cooper Bridge, the young man removed to Marsden, and entered the service of Messrs. Taylor Brothers, engineers and boilermakers. In 1834 he entered the service of Messrs. Hibbert & Platt at the Hartford Works, Oldham, who had already acquired an excellent reputation as textile machine makers. In 1837, desiring to gain further experience and knowledge, and trade in Oldham being slack, William Richardson left that town for London, and succeeded in obtaining employment with Messrs. Beal & Henderbury, East Greenwich, where he learned the use of gauges and templets, and obtained an insight into the principles of interchangeability and accurate workmanship, which he never afterwards forgot. After working in London about six months, he returned to the Hartford Works, where he applied himself with such diligence and success to the remodelling of the scutcher department that his employers advanced him to a leading position in the management of the business. From this time the career of Mr. Richardson becomes part of the history of Hartford Works. After the building of Hartford New Works, the growth of the business led to the establishment of

various outside branches—such as the forge for the manufacture of wrought iron, the brick-works for the manufacture of patent bricks, and the collieries and coke ovens. With all of these Mr. Richardson was specially associated, taking a leading part in their installation and development, and on all of them he has left the impress of his judgment and ability.

Although the records of the Patent Office show that Mr. Richardson was a prolific inventor, it was more in the character of constructor and organizer that his strength lay. A skilful handicraftsman, capable of enduring the most exhausting fatigue, well informed on all matters connected with his business, and possessed of sound judgment, indomitable resolution, perseverance, and the love of his calling, he was, in cases of difficulty, full of resource, and a tower of strength.

Mr. Richardson took great interest in the progress of his adopted town, of which he was a borough magistrate, and, for a time, a town councillor, promoting its educational interests, especially in the direction of technical education, as President both of the Oldham Lyceum and of the Oldham Science and Art School. He was a generous benefactor to the Oldham Infirmary. He was a member of the Iron and Steel Institute from its foundation in 1869, and for a number of years acted as a member of Council. Mr. Richardson was a member of other scientific and technical institutions, including the Institution of Mechanical Engineers.

The business of Hartford Works was, in 1837, changed from the style of Hibbert & Platt to that of Hibbert, Platt & Sons. In 1854, Messrs. John and James Platt, having become sole proprietors of the business, decided, in consequence of its growth, to enlarge the partnership by admitting the chief heads of departments, viz., Mr. William Richardson, Mr. William Frederick Palmer, and Mr. Edmund Hartley, the style of the firm becoming Platt Brothers & Co. In 1868, the business was transformed into a limited liability company, Mr. Richardson becoming Vice-Chairman, and having the satisfaction of seeing his elder son, George, taking his place as a director at the same Board as himself. Mr. Richardson continued to hold the position of Vice-Chairman until the time of his death. At the age of twenty-nine he married Mary, the eldest daughter of Mr. John Gartside, woollen manufacturer, Cherry Clough, Saddleworth. His death took place at his residence, Werneth, Oldham, on the 16th December 1892, at the age of eighty-one.

✓HERMANN LUDWIG LANGÉ was born at Plauen, in Saxony—where he was educated—on the 10th of May 1837. At the age of seventeen he went to Berlin, and there served an apprenticeship for three and a half years with a leading engineering firm, then employed in the construction
1892.—ii.

of stationary engines, turbines, and water-wheels, during which time he was frequently employed in delivering and erecting machinery.

On leaving Berlin, he went to the Polytechnic School at Karlsruhe, where he spent two years in a course of study in civil and mechanical engineering.

In 1861, invited by the late Mr. Beyer, a townsman of his own, he came to England, and entered the engineering works of Messrs. Beyer, Peacock & Co., locomotive and machine-tool makers, Gorton Foundry, Manchester, being first employed in the workshops for about a year, and afterwards in the drawing office.

In the drawing office, he was at first chiefly engaged at machine-tool designs, under Mr. Beyer's personal direction, and it was not long before he showed that he possessed marked mechanical instincts. Subsequently, he was occupied on locomotive designs, and the experience thus gained enabled him, about the year 1864, on a vacancy in the position of head draughtsman occurring, to take charge of the drawing office. This position he held until Mr. Beyer's death in 1876, when he became chief engineer to the firm, and co-manager.

On a vacancy occurring in 1888, on the Board of Directors of the Company—which in 1883 had been converted into a limited company—Mr. Langé was appointed a Director.

The marked features of Mr. Langé's character were great physical and mental energy, and conscientious thoroughness in all he undertook. He spared no personal labour in perfecting detail, even to the smallest minutiae. He possessed a sound judgment in mechanical questions, and a true appreciation of the fitness of details. This was especially shown in the carrying out of designs for tramway engines and rack locomotives for steep inclines, which, on account of the special conditions that these two classes of locomotives have to fulfil, presented more difficulties of detail than usually occur in ordinary locomotives.

Mr. Langé, it may be said, fell a victim to his own restless energy of temperament. He had naturally a strong constitution, but, as the result of over-application to work, his health had been failing for several years, and about three months prior to his death he was prostrated by an attack arising from feeble action of the heart. He was then advised by his doctor and friends to take a long rest from business. This advice, however, he disregarded, and after a short rest, and while still in feeble health, he returned to work. For a few weeks he took things comparatively easy, but on regaining some measure of strength, he pursued the duties of his position with much of his accustomed energy, with the result that was only to be anticipated. He left Gorton Foundry at four o'clock on January 14, 1892, after a day's close application to business, and, while at home an hour or two later, engaged in writing a letter, he was seized with a stroke of paralysis, and expired the same night. He

was a member of the Institution of Mechanical Engineers, and became a member of the Iron and Steel Institute in 1891.

PHILIP WILLIAM FLOWER, J.P., who died on March 26, 1892, at his residence, Baglan Lodge, near Briton Ferry, in his fifty-fourth year, was well known as a tinplate manufacturer, having, in conjunction with Mr. Leach and others, built the Melyn Works in South Wales about twenty-seven years ago, and having acted as the managing partner of that establishment since its commencement. The firm, which was known as Leach, Flower & Co., were among the first to introduce into Wales the printing and decorating of tinplates. Mr. Flower was, before building the Melyn Tinworks, a managing partner of the Margam Tinplate Co. He was, besides, a managing partner of the Copperminers' Tinplate Works at Cwmavon, and was for some years Chairman of the Tinplate Association. He was considered an authority on tinplate manufacturing, having been the author of several books and pamphlets on the subject. Deceased was the second son of Mr. John Wickham Flower, Park Hall, Croydon, and went to Wales in 1859. He became a member of the Iron and Steel Institute in 1880, and in 1886 he contributed a paper to the "Proceedings" on the "Origin and Progress of the Manufacture of Tinplates," which showed that he possessed a considerable literary vein.

WALTER WILLIAMS, who died on Saturday, the 5th of March 1892, at Pau, was born in 1830, and had consequently reached the sixty-second year of his age. His father was a member of the firm of Philip Williams & Sons, of the Wednesbury Oak Ironworks, Tipton. These works had for many years occupied a prominent position in the South Staffordshire iron trade, having been erected in the earlier part of the present century by Philip Williams, who was at that time in partnership with Benjamin Gibbons.

In 1816, Philip Williams became the sole owner of the Wednesbury Works, but at a later date he assumed his sons, Philip and Walter, as partners, and the firm thereupon took the style, which it has since retained, of Philip Williams & Sons. Mr. Walter Williams was a son of Walter, the brother of Philip Williams, and, on the death of the latter, in 1864, he was entrusted, jointly with his brothers, Joseph W. Williams and P. A. Williams, with the management of the works and collieries belonging to the firm, in which position he continued until the time of his death.

The Wednesbury Oak Works have long been among the largest in South Staffordshire, embracing collieries, blast-furnaces, and finished iron-works. The firm also carried on for many years works known as the Union Furnaces at West Bromwich, but some sixteen years ago this latter property was disposed of to the Stour Valley Coal and Iron Company, which

was subsequently dissolved. The property then reverted to the original owners, who carried it on under the style of Philip Williams & Company, until the furnaces, having become antiquated, were discontinued.

Besides the several works named, the firm carried on manufactured iron-works, and engaged in the mining industries of Smethwick and Bilston, which were administered successfully for a number of years. On the establishment, in the year 1863, of the South Staffordshire Ironmasters' Association, Walter Williams undertook the office of honorary secretary, and he acted in this capacity for several years, during which time the Association increased in membership and influence. He was succeeded in this office by the late Mr. John Jones, who, at a later date, became secretary to the North of England Ironmasters' Association, and to the Iron and Steel Institute.

Mr. Walter Williams held for several years the position of Chairman of the South Staffordshire Ironmasters' Association, and he also filled for a term the office of President to the Mining Association of Great Britain. For a number of years he was also Chairman of the South Staffordshire District Bank, an office which gave him a considerable amount of prestige in that locality.

From 1877 to 1888 Mr. Williams held the position of Chairman of the South Staffordshire Mines Drainage Commissioners, and assisted materially in the passing of the first of the South Staffordshire Mining Drainage Acts in 1873. The drainage area affected by this Act was from 95,000 to 100,000 square miles in extent, and comprised almost the whole of the South Staffordshire coalfield. It was estimated at that time that 150,000,000 tons of coal and 17,000,000 tons of ironstone were flooded within this area. The Drainage Commissioners began operations in 1873, over an area of about eighty square miles, part of the district having been withdrawn from their control. The work of the Commission was divided into surface drainage and mines drainage, and rating powers were obtained which extended over a great part of the South Staffordshire coalfield, thereby enabling the very considerable cost of instituting operations to be defrayed.

The cost of pumping the water within this area for several years varied from 1d. to 1½d. per ton, but latterly, the tonnage having been reduced, it rose to about 3½d. per ton. The pumping engines controlled by the Commission had, during the three years ending with 1891, averaged 644,000 gallons per twenty-four hours. In the important work carried out by the Commission, Mr. Walter Williams personally took a most prominent part until December 1888, when, on personal grounds, he resigned his position.

In 1874, Mr. Williams stood as a candidate in the Conservative interest for Wolverhampton, but was defeated. He was one of the

original members of the Iron and Steel Institute, and in 1872 he was elected a member of the Council—a position which he held until 1878. He took a considerable interest in, and was a tolerably regular attender at, the earlier meetings of the Institute, and he took some part in the discussion of papers read in 1869 and 1871. He was a Justice of the Peace for South Staffordshire, and a Doctor of Laws. Of late years he did not enjoy good health, and it was with a view to improving his condition that he proceeded to Pau, where he died.

MASKELL WILLIAM PEACE, who died at Southport on 9th November 1892, was the son of the late Mr. William Peace, who was formerly the mineral agent for the late Earl of Crawford. He was born in Wigan on 3rd April 1834, was educated at Rossall School, and, on leaving that establishment, was articled to the late Mr. John Mayhew, solicitor, of Wigan. On completing his articles, Mr. Peace was admitted a solicitor in Trinity Term 1855, and commenced business on his own account in an office in Standishgate, Wigan. Subsequently he removed to 10 King Street, and having taken into partnership Mr. Herbert Booth Bell, the firm was carried on under the style of Peace & Bell. This partnership was dissolved after a few years, on Mr. Bell removing to London. Mr. Peace then entered into partnership with Mr. Henry Ackerley of Wigan, and Mr. William Appleton of Oswestry, and this partnership was carried on under the style of Peace, Ackerley & Appleton, at Leader's Buildings, King Street. Mr. Appleton shortly afterwards retired from the firm, and the business was conducted under the style of Peace, Ackerley and Co. About 1883 this partnership was dissolved, and Mr. Peace joined Mr. Thomas Ratchiffe Ellis, the surviving partner of the firm of Scott and Ellis, and the combined businesses have since been carried on under the style of Peace & Ellis.

Mr. Peace held numerous public appointments, and filled them with ability. His services as secretary of the Wigan Mining and Mechanical School, from its foundation in 1858 to the present time, will long be remembered in the local history of technical education. He was appointed law clerk and secretary of the South Lancashire and Cheshire Coal Association on the 3rd April 1861, and acted in that capacity up to the time of his death. He was appointed solicitor to the Mining Association of Great Britain in February 1866, becoming secretary of the Association in February 1870, and he acted as law clerk and secretary up to the time of his death.

He was for many years identified with the municipal life of Wigan, first as a councillor, and subsequently as town clerk—a position he filled for a period of more than eighteen years, viz., from 24th September 1866 to 31st March 1885. On the occasion of his retirement from this

office, he was presented by the members of the Town Council, and the leading officials of the Corporation, with a beautiful piece of plate and an illuminated address. He was shortly afterwards appointed an alderman of the borough, and was more than once invited to accept the Mayoralty, which he was compelled to decline owing to the state of his own and of his wife's health. On the day of his death he was appointed returning alderman of one of the wards, and his name was placed on several committees. He represented Wigan on the County Joint Committee to enforce the provisions of the Rivers Pollution Prevention Act, 1876, in relation to the river Ribble. He was returned unopposed to the Lancashire County Council as the first Councillor representing the Standish Division, and, on his term of office expiring, was again elected without opposition. He was also appointed Chairman of the Parliamentary Committee of the Council, a position which his abilities and reputation eminently qualified him to fill.

Mr. Peace was the author of several books relating to mining law, and his works on the Coal Mines Regulation Acts and the Truck Acts were accepted as authorities on these subjects. On all questions affecting the law of minerals he was an admitted authority, whilst on questions arising on Private Bills in Parliament his opinion was frequently sought in the interests of coalowners, property owners, and traders generally, with the view of obtaining protective clauses. In connection with the Railway and Canal Traffic Act, 1888, Mr. Peace was actively engaged, as representing the Mining Association, on the Board of Trade inquiry into the revised schedules and classifications of the various railway companies, and, subsequently, on the inquiry before the Joint Select Committee of Lords and Commons on the Provisional Order Bills which were brought in to confirm those schedules. Mr. Peace was engaged up to the time of his death in the Board of Trade inquiry into the revised schedules of the various canal companies, and railway companies owning canals. As a conveyancing lawyer, particularly as regards mining leases, he was also an authority. He was the Secretary to the Board of Examination for mine managers certificates for the districts of North and East Lancashire and Ireland, and West Lancashire and North Wales. He was appointed solicitor and secretary to the Lancashire and Cheshire Coalowners' Defence Association on the establishment of that organisation in June last.

At the last annual meeting of the Manchester Geological Society, Mr. Peace was appointed President of that body for the ensuing year. Amongst his numerous other appointments he was the solicitor for the Lancashire and Cheshire Miners' Permanent Relief Society, the Central Association for dealing with Distress caused by Mining Accidents, and the Colliery Managers' Association, while in addition to his public appointments, he was the secretary of the Wigan Coal and Iron Com-

pany, Limited, from the beginning of 1870, as well as secretary to the Cossall Colliery Company, Limited, Nottingham, since its formation in 1877, and to the *Colliery Guardian* Company, Limited.

Mr. Peace was a prominent Freemason, and when the Volunteer movement was originated in the Wigan district, he interested himself in connection with it, and was appointed Lieutenant of the Haigh corps. He had been a member of the Iron and Steel Institute since 1876.

PERCEVAL M. PARSONS, who died at his residence, Melbourne House, Blackheath, in November 1892, at the age of seventy-three years, was chiefly known for his patents for improvements in ordnance, several of which were adopted by the War Office, and more recently as the inventor of manganese bronze, an alloy now very extensively used on account of its great strength. He had from first to last introduced a number of inventions to public notice, amongst his ordnance inventions being a system of inserting rifled steel tubes into the then useless old cast-iron guns, with a view to making them serviceable, and a bolt for fish and armour plates, which was favourably reported upon in England, and was adopted by the Russian Government, as well as other inventions and proposals.

When he had satisfied himself, in 1860, that his proposed system of providing new liners would render the old cast-iron guns available for service, Mr. Parsons laid his invention before the Ordnance Committee, who made an attempt to carry it out; but they did not report favourably on it, and, believing that his invention had been rejected, Mr. Parsons allowed his patent to lapse. In 1862, Captain Palliser patented an almost similar system of converting guns, which the Ordnance Committee finally adopted. Mr. Parsons thereupon put in his claim to be the original inventor of the system, and, after much effort to secure a recognition of his rights, he received from the War Office a certain amount of compensation, Mr. Charles Hutton Gregory, to whom the matter was referred, having, as arbitrator, decided that the claims of Mr. Parsons were just and equitable.

Proposals were at an early date submitted by Mr. Parsons for the construction of a central London railway, which was to follow very nearly the course of the present Metropolitan District line, and to have connections with most of the other Metropolitan systems. One feature of the scheme was to be the construction of a large central station on the present site of the Embankment Gardens, with platforms for each of the chief companies. Robert Stephenson approved the proposal, and accepted the position of consulting engineer, while Mr. John (afterwards Sir John) Hawkshaw was to be the chief engineer, and Messrs. Parsons and Berkley were to be the acting engineers. But the scheme was never carried out, mainly because the attention of the public was diverted, by the Crimean war and other matters then pending, to other forms of enterprise.

Mr. Parsons was a son of Mr. John Parsons of Scraptoft, Leicestershire, and received his early education from the Rev. J. Dallen, of Shooter's Hill, Kent. He afterwards studied for two years at Portsmouth Dockyard, and thence proceeded to London, where he was articled to Messrs. Braithwaite & Milnes. Having been employed on engineering work for a time—first with Mr. John Rennie, and afterwards with Mr. Peter Bruff—he undertook to make the surveys on a branch line of the Eastern Counties Railway, and finally set up in London on his own account as an engineer. He was a man of very honourable and straightforward character, and had many friends.

HENRY J. MARTEN was born in February, 1827, at Plaistow, Essex. He was articled to Mr. Wickstead, the eminent engineer, and was the resident engineer under Mr. Wickstead during the construction of waterworks in Hull, and subsequently of the first Wolverhampton Waterworks. He continued with the latter company as their engineer for some years after the completion of the works.

Amongst other local works constructed by Mr. Marten were the Wolverhampton Waterworks extensions at Goldthorn Hill and Cosford, the Stourbridge District Waterworks, the Wellington (Shropshire) Waterworks, the Bridgnorth Waterworks, the South Staffordshire Waterworks (in partnership with the late Mr. Maclean, M.P.), the Tamworth District Waterworks, the West Gloucestershire Waterworks, the Dudley Sewage Works, the Tipton Sewage Works, and Tettenhall Sewage Works.

He was engineer to the Severn Commissioners, and at the time of his death was carrying out a very important scheme of improvement in the navigation of that river. He was also consulting engineer to the Corporation of West Bromwich with respect to their sewage works, and he acted as consulting engineer to the Board of Agriculture, and to their predecessors, the Land Commissioners, the Corporation of Walsall, the York Waterworks Company, the Thames Conservators, the Staffordshire and Worcestershire Canal Company, and other important bodies.

At the instance of an influential body of traders in the district, he some years ago made a complete survey of the waterways between Birmingham and London, and submitted an exhaustive report, setting forth a scheme for their improvement. He was also consulted by the Leeds and Liverpool Canal Company with respect to proposed improvements. He had been for many years one of the statutory arbitrators under the South Staffordshire Mines Drainage Acts.

In Parliamentary work and arbitrations, Mr. Marten was much sought after. He was usually retained in all the important water cases before Committees, one of his latest retainers being on behalf of the Corporation of Birmingham, in connection with their Water Bill of last session. His

most recent important appearance in public was in the autumn of 1892, when he gave evidence before the Royal Commission on metropolitan water supply.

He married, first, the only daughter of the late Mr. E. B. Dimmack, ironmaster, J.P. and D.L. for Staffordshire and J.P. for the borough of Wolverhampton, who also served as High Sheriff for Monmouthshire about forty years ago. He had four sons, three of whom are living, and three daughters, all living, by her. For many years he carried on the Parkfield Ironworks in partnership with Mr. Dimmack. His second wife was the widow of the late Mr. William Pilkington, J.P., of Blackburn and Wood End, Yorkshire.

Mr. Marten had two brothers living, the elder being Mr. A. G. Marten, Q.C., and the younger Mr. E. B. Marten of Stourbridge, the latter of whom is the engineer to the South Staffordshire Mines Drainage Commissioners and other corporations.

He was a member of the Institution of Civil Engineers, a member of Council of the Royal Meteorological Society, and a fellow of the Geological Society. He was an original member of the Iron and Steel Institute. He died on the 3rd November, 1892.

THOMAS W. CRAWHALL-WILSON, who died at his residence, Alston House, on 25th April 1892, was the oldest son of the late Mr. Isaac Crawhall, of Nun Monkton, Yorkshire. The family from which he was descended was of old standing in the dales, and had been long connected with the lead mining industry. Mr. Crawhall-Wilson for a time was managing partner of Hudgill Burn and also of Rodderup Fell, two of the most productive mines in the Alston Manor. He was also the managing partner in Coanwood Colliery, and Chairman of the Solway Iron Coy., Maryport. He qualified as a Cumberland County Magistrate in 1876. He adopted the additional surname of Wilson, and acceded to the Nent-hall estate and other properties on the death of his uncle, Mr. Wilson of Shotley Hall, in 1880.

The deceased was for a number of years connected with the Alston Rifle Volunteers, and attained the rank of Captain. He was an ardent Conservative politician, and held at his death the offices of President of the Alston Union Club, and of ruling councillor of the local Primrose League. Although Mr. Crawhall-Wilson has rarely been in robust health, he was admittedly a shrewd and able business man. His relations with his workmen were generally of the best, and if we except the Coanwood colliery strike of 1890, the firms with which he was connected seldom had a dispute with their men. As a magistrate he was ever disposed to treat offenders with such leniency as was compatible with duty, and never pronounced a severe sentence unless in cases marked by

the worst features. His consistent practice in this respect gave force to his remark on one occasion, that he "would well wish to see a spider web woven over the door of the district lock-up." He was an enthusiastic politician, and an effective platform speaker. He had been a close student of political questions from his youth, and, having a most retentive memory, was an admitted authority on Parliamentary and party topics. He had travelled widely. About half-a-dozen years ago he wintered in the West Indies. In the autumn of 1890 he visited the United States and Canada, as a member of the Iron and Steel Institute. It is believed that this journey, with its long mileage of railway travel, its continuous sight-seeing, bustle, and unrest, told heavily on a constitution never very robust. Mr. Crawhall-Wilson returned to England in delicate health, and he does not appear since to have acquired tone and stamina, though he was generally sufficiently well to meet his business engagements. Deceased was in his 67th year. Mrs. Crawhall-Wilson survives her husband, as well as five sons and two daughters.

JOHN VARLEY, of the Leeds Forge Company, Leeds, was born in that town on the 7th August 1828, and died at the Adelphi Hotel, Liverpool, from syncope, on the 17th November 1892.

Mr. Varley commenced business, when fourteen years of age, at the works of Messrs. Maclay & Maish, of Holbeck, Leeds. He soon rose to be assistant-manager of the works, and from there he proceeded to the Clarence Iron Works of Messrs. J. Whitham & Sons, of Leeds, whom he represented for three years, or thereabouts. Leaving Clarence Works, when about thirty years of age, he became manager and chief draughtsman for the London firm of Hepworth & Sons, whence he transferred his services to Messrs. C. Cammell & Company, of Sheffield. He ultimately became connected with the Farnley Iron Company. At that time there was not much talk of mild steel superseding the old Yorkshire iron, but the change came about sooner than was expected, and Mr. Varley having removed from the old Farnley Iron Works to the Leeds Forge, had to face there the problem of producing steel on the open hearth. He did this with notable success, and he had gone on a business visit to Liverpool, in connection with the Leeds Forge, when he died. He was a member of the Institution of Mechanical Engineers, of the North-East Coast Institute of Engineers and Shipbuilders, and of the Iron and Steel Institute, which he joined in 1886. He was also an associate of the Institution of Naval Architects.

✓ Sir JAMES BRUNLESS, who died at Wimbledon on June 2, 1892, in the seventy-seventh year of his age, was born at Kelso, Roxburghshire, on January 5, 1816. After leaving school he was put by his father to

gardening and farm work, with the view to his taking up the duties of a landscape gardener. This occupation, however, was not congenial to his tastes, and having himself earned enough to carry out his wish, he went to Edinburgh University for two sessions, and there took up civil engineering, being first employed in 1838 as assistant to the late Mr. Alex. Adie on the Bolton and Preston Railway. At a later date he joined the staff of Messrs. Locke & Errington, and took an important part in laying out the Caledonian line from Beattock to Carstairs, with branches to Edinburgh and Glasgow. On the completion of this work, he was offered the post of acting engineer on the Lancashire and Yorkshire Railway under the late Sir John Hawkshaw, engineer-in-chief. In 1850 he went to Ireland, where he was employed on the Londonderry and Coleraine Railway. Two years later, he undertook the engineering work of the Ulverston and Lancaster Railway across Morecambe Bay, which involved heavy embankments and several iron bridges. In addition to acting as arbitrator in the settlement of disputed contracts and other railway matters, Mr. Brunless carried out a number of public works, including the Solway Junction Railway, which comprised a viaduct of a mile and a quarter in length over the Solway Firth; the Clifton Extension Railway; the Mersey Tunnel Railway between Liverpool and Birkenhead (in connection with which he received, in May 1886, the honour of knighthood); the Mont Cenis Summit Railway (which involved very steep gradients); the Avonmouth, King's Lynn, and Whitehaven docks; the Southport, New Brighton, and Llandudno piers, and the new pier and pavilion at Southend. Among his principal works abroad were the Central Uruguay, San Paulo, Bolivar, and other railways in South America.

Sir James was joint-engineer with Sir John Hawkshaw for the Channel Tunnel scheme. He became a member of the Institution of Civil Engineers in 1872, and at a later date he was elected to the office of President of the Institution. He was also a Fellow of the Royal Society of Edinburgh. He joined the Iron and Steel Institute in 1872, but seldom took any part in its deliberations.

GEORGE GRANVILLE LEVESON GOWER, K.G., Duke of Sutherland, who died at Dunrobin Castle, Ross-shire, on Thursday, September 22, 1892, was eldest son of the second Duke and of Lady Harriet Elizabeth Georgina, daughter of the sixth Earl of Carlisle. He was born in 1828, and succeeded to the titles and estates on the death of his father in 1861. In the peerage of Scotland he was Earl of Sutherland and Baron Strathnaver; in the peerage of England he was Baron Gower; in that of Great Britain he was Earl Gower, Viscount Trentham, and Marquis of Stafford; while in that of the United Kingdom he was Duke of Sutherland, his father having been advanced to that dignity in 1833.

In 1849, when Marquis of Stafford, the late Duke married Anne, only child of Mr. John Hay Mackenzie, of Cromartie and Newhall, who was created Countess of Cromartie in her own right in 1861, in token of Her Majesty's great personal regard for her. The late Duchess was also Mistress of the Robes to the Queen from 1870 till 1874. On her death in 1888 she was succeeded in her titles and estates by her second son, the present Earl of Cromartie. In 1889 the Duke married, as his second wife, Mary Caroline, widow of Mr. Arthur Kindersley Blair, and daughter of the late Rev. Richard Michell, D.D., Principal of Hertford College, Oxford.

The late Duke was Lord-Lieutenant of the counties of Sutherland and Cromartie. He was for a time Honorary Colonel of the 11th Duke of Cambridge's Own (Middlesex) Regiment. As Marquis of Stafford he represented Sutherlandshire in the House of Commons from 1852 till 1861. He was long known as one of the most liberal and enterprising of Scottish landowners, and he took very public-spirited action in the reclamation of waste lands, and the extension of railways and railway traffic, in the northern counties of Scotland. It has been stated, moreover, that no Scottish landlord, of recent times at least, has expended such large sums of money on the improvement of his estates, and that this was done much less with an eye to profit than from a disinterested desire to improve the land, to develop the resources of the country, and to promote the comfort and well-being of the people living, not only on his own estates, but throughout the North of Scotland.

The inquiry of Lord Napier's Commission some years ago brought out the fact that, during the thirty years from 1853 to 1882, the late Duke and his father had spent on "estate works" at Dunrobin a sum of £637,300. Subsequently the late Duke embarked on a project for the reclamation of waste lands at Lairg and at Kildonan, on which he expended £254,900. These works have not yielded the return that was expected from them, but they gave employment to a large number of local labourers, and they are a monument to the energy and liberality of their projector. The Duke also expended nearly £50,000 on the coal-mines at Brora, and on steam sawmills and brickworks, with the view of developing and encouraging local industries. His liberality and enterprise were quite as conspicuous in the prominent part he took in extending the railway system to the northern counties. He invested largely in the original Highland Railway, and was one of the chief promoters of the extension of that line from Dingwall to Strone Ferry. He is even more closely identified with the extensions of the Highland main line north of Bonar Bridge, and it has been said that, but for him, these extensions would not have been carried out. To the expense of the first section—from Bonar Bridge to Golspie—he contributed £94,200. The second section—from Golspie to Helmsdale—was made entirely at his

expense. It cost £72,100, and is very properly known as "The Duke of Sutherland's Railway." To the cost of the third section—from Helmsdale to Wick, with a branch to Thurso—he contributed £60,000. Thus those sections of railway received from him no less a sum than £226,300, and the interest he received in return amounted to only 2 per cent. per annum.

The connection of the family with Staffordshire led the Duke, as well as his father, to take an interest in the development of the railway system in England.

The late Duke's father was one of the most liberal supporters of the Liverpool and Manchester Railway, when it was commenced, and, in consideration of the valuable financial assistance which he rendered at that time, arrangements were made for having the father, and the son after him, permanent directors of the Company, in accordance with which the late Duke sat for a great part of his lifetime as a director of the London and North-Western Railway. He was also largely interested in the mineral industries of Staffordshire, being one of the proprietors of the Lilleshall Works in Shropshire, and having an interest in other undertakings. He took a considerable interest in metallurgical progress, and after he became a member of the Iron and Steel Institute in 1872, he now and again attended the meetings, but never took any more prominent part in the proceedings. One of the most notable incidents in the life of the late Duke was his visit to India, in company with the Prince of Wales, in 1876. He had the honour on more than one occasion to entertain the Queen and the Prince and Princess of Wales at Dunrobin. He cordially supported the Suez Canal scheme, and was present at the opening ceremony.

ISAIAH BEVAN, who was killed at Llanelly, South Wales, on Tuesday, the 17th of January, by the falling of a lot of pig iron which was being loaded at the docks of that town, was well known in South Wales as an enterprising and successful manufacturer and man of business.

The deceased gentleman was the eldest son of Mr. John Bevan, Brynrhos, Llanelly, and was born about forty-one years ago. His early years were spent at the Heolfawr School, and shortly afterwards he was apprenticed as a pattern-maker at the Wern Foundry. His training here gave him a practical insight into business, which was a large factor in his later success. He spent some time out of the town, but subsequently returned and joined his father in extensive chemical works at the New Docks. Bringing to bear upon this undertaking the whole of his energies, the business soon developed, and a few years ago another manufactory was erected adjacent to the Old Castle Tinplate Works. Nor was Mr. Bevan's connection confined to chemical manufactories. He had a large interest in the Burry Tinworks, and recently was appointed on the board of directors.

Mr. Bevan came from an old Nonconformist and Liberal family, and at the last parliamentary election he worked unceasingly for the return of the Gladstonian candidate, and was largely responsible for the preponderance of votes cast for the Liberal candidate in the seaside and new dock districts, where he was especially popular. For some time he occupied a seat on the Local Board and Harbour Commissioners, but relinquished this, and at the last County Council election (March 1892) he was returned for Ward No. 3. He devoted himself assiduously to the work of the Council, and was proving himself to be a useful member. Until recently, he was the secretary of the Llanelly Chamber of Commerce, and only retired owing to the numerous calls upon his time. He still continued to be a regular attendant at the monthly meetings, and he took a prominent part in the movement for improving the shipping facilities of the port.

Mr. Bevan was an ardent sportsman, and his figure could often be seen on the cricket-field. He was in complete accord with the aspirations of the Welsh people. The recently formed Cymrodorion Society found in him a supporter, and he was unanimously elected to the treasurership. At the fortnightly meetings he was a constant attendant. As a large employer of labour, Mr. Bevan was in a position to know the extent of the present depression, and he was one of the first movers in the direction of providing measures of relief. He was a member of the Joint-Standing Committee of the Carmarthenshire district, where his services were appreciated.

He was married to Miss Bishop of Swansea, who survives him.

✓ WILLIAM POWELL SHINN was born in Burlington, New Jersey, May 14, 1834. He began his professional life as a civil engineer in 1849, and was for a time engaged in making surveys for county maps in Massachusetts and Rhode Island. In May, 1850, he entered the service of the Ohio and Pennsylvania Railroad. He rapidly passed through the intermediate grades, and in August, 1852, was appointed assistant-engineer in charge of a division of the road. In the following April he became principal assistant-engineer in charge of the location and construction of eighty-three miles of the Fort Wayne and Chicago Railroad. In February 1885 he practically abandoned the active practice of railway location and construction, and began to occupy himself with the details of traffic and general management of railways by taking charge of the freight department of the Ohio and Pennsylvania Railroad Company. From October, 1856, to September, 1861, he held various responsible positions in the accounting department of the Pittsburgh, Fort Wayne, and Chicago Railroad Company. In September 1861 he took charge of the passenger department; in September 1863

he was made superintendent of the passenger department; and in October 1865 he was made the head of the freight department.

When the Pennsylvania Company was organised, Mr. Shinn was appointed as an expert to examine the affairs and conditions of the various companies interested in the lease to the Pennsylvania Company. From May, 1871, to May, 1873, he had charge of the construction of the Ashtabula, Youngstown and Pittsburg Railway Company, and in 1873 he became president of that road. In 1874, he was vice-president of the Allegheny Valley Railway Company.

From January, 1873, to October 1, 1879, Mr. Shinn acted as the managing partner of Carnegie, M'Candless, & Co., and had charge of the building and operating of the Edgar-Thomson Steelworks. In 1879-80 he reorganised the Vulcan Steel Company of St. Louis, and rebuilt and started these works. From 1881 to 1887 he was vice-president of the New York Steam Company, for the distribution of heat by steam through the streets of New York. From December, 1886, to December, 1889, he was vice-president in responsible charge of the New York and New England Railroad Company, and in 1888-89 he was president of the Norwich and New York (steamboat) Transportation Company.

Mr. Shinn was elected a member of the American Society of Civil Engineers on September 15, 1869, and on January 15, 1890, he was made its president. In 1875 he was elected a member of the Institute of Mining Engineers, his leading proposer being Alexander L. Holley. In 1876 and 1877 he was one of its vice-presidents, and in 1880 he was elected president.

His contributions to the "Transactions" of the last-named Society include, besides remarks in discussion, the following papers:—"Pittsburg, its Resources and Surroundings" (1879, viii. 11); "The Advance in Mining and Metallurgical Art, Science, and Industry since 1875" (Presidential Address, February 1881, ix. 293); "The Distribution of Steam in Cities" (1884, xii. 632), and "The Genesis of the Edgar-Thomson Blast Furnaces" (1890, xix. 674). But these published papers by no means represent the amount of his labours. His special ability, developed in wide and various experience as a railroad engineer and manager, as director of the Edgar-Thomson Steelworks, and in the difficult and novel business of the New York Steam Company (to mention no others), was in the organisation and control of complicated undertakings.

In 1890, the Institute of Mining Engineers, and the societies and trades co-operating with it in the reception of the Iron and Steel Institute, and other foreign guests, needed just such a man as Mr. Shinn, and he, in response to their call, leaving positions of less laborious, but more conspicuous, service to be filled by others, accepted the chair-

manship of the Sub-Committee on Transportation of the General American Reception Committee. The arduous, vexatious, exhausting, and unremitting labours of that position cannot be adequately described. Their results, in the unprecedented excursions of more than five hundred guests over thousands of miles, extending from Lake Superior to Southern Alabama, and keeping several Pullman trains in continual use for weeks—securing not only the collective safety, but also the individual comfort of the travellers—have been the topic of general wonder and praise. To those who knew that in the midst of the preparations for those intensely busy weeks, Mr. Shinn was overwhelmed by the greatest sorrow that could befall him, in the death of his tenderly-beloved wife—from whose grave he turned to resume the work from which at that late stage he could not be spared without disaster—the spectacle of his unwearied zeal and efficiency was all the more impressive. Mr. Shinn carried through his task to the grateful admiration of all, and this Institute awarded an appropriate testimonial to the marvellous executive ability which had done so much for their convenience and comfort; while his American colleagues were not backward in confessing their debt to him for the one feature which made the international meeting of 1890 unique.

Mr. Shinn had been a member of the Iron and Steel Institute since 1878, and had looked forward to visiting England in the summer of 1892.

JAMES ALLAN was born at Johnstone, near Glasgow, in 1837. He came to Coatbridge about 1846, and shortly thereafter entered the employment of Messrs. Wilson & Co., Dundyvan Ironworks. At a later period he acted for a time as an engine-driver on the then newly-opened Monkland Railway. He learned the business of tubemaking in the service of the Caledonian Tube Company, and in 1860 he was offered and accepted an important situation with Messrs. Marshall and Wylie, of Glasgow Tube Works. In 1869, Mr. Allan leased the Coals Tube Works, Coatbridge, where he started business on his own account. His enterprise in these works turned out so successfully that in 1879 they were found too small, and he accordingly built the Victoria Tube Works, Coatbridge, which were specially adapted for the manufacture of iron and steel boiler tubes, and for boiler tube ferrules. In 1883 Mr. Allan founded the Woodside Steel and Iron Works for the manufacture of tube strips and plates.

He accompanied the Iron and Steel Institute to the United States, and was much interested in what he saw. In returning from America he had the misfortune to be a passenger on board the *Ethiopia*. On the voyage this vessel broke her shaft in mid-Atlantic, and was for several days in imminent danger, the voyage altogether occupying twenty-four days. His death took place on 19th March 1892.

NOTES

ON THE PROGRESS OF THE

HOME AND FOREIGN

IRON AND STEEL INDUSTRIES.

II.—1892.

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ABSTRACTORS.

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IRON ORES.

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I.—OCCURRENCE AND COMPOSITION.

The Hæmatite Ores of Cumberland.—Mr. J. L. Shaw* describes the hæmatite ores of Cumberland, and notes their occurrence in the granite, the syenitic granites, the Skiddaw slates, the volcanic series, the Coniston limestone, the basement conglomerate beds, and in the Carboniferous limestone, the latter being the most important ore-bearing horizon. The various systems of faults are mentioned, and then the author deals with the form and description of some of the principal deposits, an account of the Hodbarrow mines being given as an example. The theory of the origin of the ore upheld by the author is that it was deposited from solution in caverns formed by faulting, and by the corrosive action of water in the limestone. The original source of the iron was in the ancient overlying rocks, that have since been largely denuded. The rate of deposition was greatest in the coal-measure period, but it is considered that the hæmatite was formed and consolidated, and afterwards carried to lower levels and redeposited. This theory is attacked by Mr. J. D. Kendall.

Frodingham Iron Ore.—Three typical specimens of iron ore from the Midland Ironstone Company's mines at Frodingham, Lincolnshire, selected for exhibition at Chicago, have been analysed, with the following results :—

* *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 580-603.

	No. 1.	No. 2.	No. 3.
Ferric oxide	46.40	32.00	38.20
Manganese oxide	1.65	1.65	1.25
Silica	8.40	6.80	4.10
Alumina	3.60	3.60	3.80
Lime	16.60	26.20	25.35
Magnesia	0.29	0.70	0.18
Sulphuric anhydride	0.14	0.06	0.07
Phosphoric anhydride	1.23	0.52	0.60
Carbonic anhydride	9.40	18.20	17.20
Combined water	12.20	10.40	9.20
Totals	99.91	100.13	99.95
Metallic iron	32.50	22.40	26.70
Sulphur	0.05	0.03	0.03
Phosphorus	0.53	0.23	0.26

These samples were taken from a 13-foot bed of iron ore; No. 1, 4 feet 6 inches from the top of the bed; No. 2, 9 feet 6 inches from the top; and No. 3, 12 feet from the top.

The Nutschitz Iron Mines in Bohemia.—The bed of iron ore at Nutschitz-Duschnik is of Silurian age, and is situated nine miles south-west of Prague.* It has the form of a long lenticular mass, trending from south-west to north-east. The dip varies from 30° to 60°, and the thickness is also extremely variable. The greatest thickness, 18 yards, is presented by the ore bed at the point where mining is now carried on.

The unweathered ore, chamoisite, is of a bluish-grey colour, and consists of a finely granular ground-mass, in which small egg-shaped granules (oolites) are embedded, with small grains of spathic iron ore between them. The proportion of iron in the raw ore averages 35 per cent. Experiments have shown that the ores average 37 per cent. in the middle and up to the roof of the 18-yard seam, whilst they average 32 per cent. near the floor.

The method of working is a variety of pillar and stall, the loss of ore not exceeding 3 per cent. The production of the mines has rapidly increased since the introduction of the basic process at the Kládno Works; for whereas in 1880 it was 48,549 tons, in 1889 it was 258,340 tons.

Hæmatite from Hungary.—In accordance with the request of the Hungarian Academy of Sciences, J. Loczka † has analysed the

* Glückauf, vol. xxviii. pp. 842-844, with illustration.

† Mathematische und Naturwissenschaftliche Berichte aus Ungarn, vol. viii. pp. 99-112.

well-known variety of hæmatite occurring in the Hargita Mountains, Kakukhegy. The specific gravity is 5.289. Qualitative analysis showed the presence of iron, oxygen, and tin. The author made six partial analyses, and the mean result was as follows:—

Iron.	Oxygen.	Tin.	Insoluble Residue.	Total.
69.92	28.99	0.52	0.15	99.58

The formula Fe_2O_3 , as is well known, demands 70 per cent. of iron and 30 per cent. of oxygen. In 1882, K. Jahn and M. Hassak * found that the composition of this hæmatite was as follows:—

Iron.	Oxygen.	Total.
70.27	29.43	99.70

Iron Ore in the Fichtelgebirge.—Professor F. von Sandberger † gives an analysis of titaniferous iron ore from the river sand at Röslau. The Eger contains this ore at several places in the form of black metallic grains, undoubtedly produced from disintegrated lithionite-granite. The colour of the ore is dark steel grey, and the specific gravity is 4.659. The ore is non-magnetic, and yielded on analysis the following results:—

Titanic Anhydride.	Ferrie Oxide.	Ferrous Oxide.	Magnesia.	Total.
48.12	24.95	27.96	0.29	101.32

The ore deposit at Arzberg, near the Bohemian frontier, which is still worked, consists chiefly of brown iron ore and chalybite. The latter contains 4 per cent. of manganous oxide. Quite recently a manganese carbonate has been discovered. It forms a thick layer on the chalybite, and has a specific gravity of 3.59. Analysis gave the following results:—

Manganese Carbonate.	Iron Carbonate.	Calcium Carbonate.	Silica.	Total.
84.41	14.22	0.54	0.40	99.57

This is the richest in iron of all the specimens of manganese-spar hitherto analysed.

Titaniferous Iron Ore in Liguria.—By chemical tests G. Vignolo ‡ has proved the existence of titanium in the magnetic sands of the Graveglia river in East Liguria, and regards it as having been derived from titaniferous iron ore.

The Iron Ores of Spain.—The iron ores of Spain, more particu-

* *Vegylani Lapok*, vol. i. p. 43.

† *Jahrbuch für Mineralogie*, 1892, No. ii. pp. 37-39.

‡ *Atti della società ligustica di scienze naturali*, vol. i. p. 322.

larly in their geological aspect, are discussed by Mr. J. D. Kendall.* The deposits in the provinces of Vizcaya and Santander all occur on about the same geological horizon, which corresponds to the Upper Greensand, and, in many features, resemble the hæmatite deposits of West Cumberland and Furness. They are mostly bed-like in form, and are regarded as products of replacement, siderite being the primary ore from which both the limonite and the hæmatite have been produced by the agency of air and oxygenated water.

In the province of Malaga the principal ore is magnetite, and is of Archæan age. These are also bedded or bed-like deposits, and may be considered to be the result of replacement by a salt of iron acting on pre-existing dolomite and subsequent metamorphism. Probably they are thus not contemporaneous with the strata in which they occur, as is generally believed. The proximate source of the iron in both Archæan and Cretaceous deposits is considered to be the adjacent rocks.

Iron Ores of Cartagena.—According to J. G. Jungner,† the iron ores of Cartagena occur in limestone. The deposits are rarely less than 20 to 24 yards in thickness. Analysis shows the ores to contain—

	Per Cent.
Ferric oxide	63·85 to 75·25
Manganese oxide	0·20 to 6·98
Phosphorus	0·02 to 0·08
Sulphur	0·16 to 0·44
Silica	12·25 to 19·05

The annual exports of these ores amount to 600,000 to 800,000 tons. The reserves of ore decrease appreciably with increasing depth. The ore is obtained by irregular open workings. The price of the ores rich in manganese is 9s. 6d. to 12s. per ton, and that of the poor ores 5s. 6d. to 6s. per ton.

The Iron Ore Deposit of Koutim.—A. Polozoff ‡ describes the iron ore deposits at Koutim, on the Vichera, in the Tcherdyn district, in the Ural Mountains. These deposits were discovered in 1874. In addition to red hæmatite in a laminated form, the same mineral also occurs in an oolitic form with a little ferric hydrate. The deposit has a thickness of from $1\frac{1}{2}$ archine (42 inches) up to several fathoms.

* *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 604–616.

† *Serukontorets Annaler*, vol. xlv. pp. 125–126.

‡ *Bulletin of the Ural Society of Amateurs of the Natural Sciences* (in Russian), vol. xii. pp. 58–59.

Trial pits showed it to have a thickness of $5\frac{1}{2}$ sagenes ($38\frac{1}{2}$ feet). The following are results of analyses made in the laboratory of the Minister of Finance:—

Description.	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Ferrie oxide	99.70	95.90	94.60
Manganese	trace	trace	trace
Sulphuric anhydride	trace	trace	0.39
Phosphoric anhydride . . . . .	...	0.02	0.04
Silica . . . . .	...	1.31	0.62
Water . . . . .	...	2.78	4.51
Iron	69.79	67.19	66.22

I. Laminated red hæmatite; II. oolitic; III. ferric hydrate.

The Iron Ore Deposits of New South Wales.—According to a report by Mr. C. S. Wilkinson,* the chief iron ore deposits are situated near Mittagong and Picton townships on the Great Southern Railway line, and near the townships of Wallerawang and Rylestone, on the Great Western Railway. These are also the most favourable localities for the establishment of smelting-works, for in them occur workable seams of coal and supplies of limestone of good quality. The Mittagong ore deposits have previously been described by the author. They are estimated to contain in sight 2,872,000 tons of brown hæmatite, yielding 48.4 per cent. of iron. The quantity of ore in sight in the deposits scattered through the outlying districts is estimated at 4,000,000 tons.

The Picton deposits consist of brown hæmatite with a little red hæmatite, their probable average depth being 25 feet, and the estimated amount of ore available being 1,362,000 tons. An average sample of the hard compact ore gave on analysis the following results:—

H ₂ O.	Fe ₂ O ₃ .	Al ₂ O ₃ .	MgO.	SiO ₂ .	Total.
13.65	71.55	10.35	0.25	4.10	99.90

Two samples of soft argillaceous ore gave—

Metallic Iron.	Silica.	Gangue.
40.35	23.00	26.35
37.56	23.80	28.95

The existence of coal near Picton has not yet been proved, but it is probable that the Mittagong coal seams will be found at a depth of 700 to 800 feet below the surface. From a small furnace, excellent iron has recently been obtained from local iron ores and coal.

* *Annual Report of the Department of Mines, New South Wales, 1891*, pp. 212-216.

The Wallerawang deposits consist chiefly of argillaceous brown hæmatite. Very little prospecting has been done to prove the lodes. One of the largest varies from 10 to 50 feet in width, and can be traced for about 750 feet. The different ores of this locality have been described by Professor Liversidge, in his work on the minerals of New South Wales.

Deposits from which iron ore could be supplied to smelting-works that may be established where the coal and limestone occur near Rylestone, are developed chiefly at Ilford, Cardwell Creek, Dungaree, and Lue. These deposits consist in each case of an oxidised capping of brown hæmatite, passing into poorer ore, containing more or less alumina and silica as impurities, and below this of a mass of ferruginous felspathic material, traversed by numerous veins of hydrated oxide of iron and hæmatite, with, in some cases, a little manganese ore. It is estimated that in these and other outlying deposits 2,226,000 tons of iron ore, averaging 43 per cent. of iron, exist in the district traversed by the Mudgee Railway.

The coal of the Mittagong field has been practically demonstrated to be suitable for iron-smelting, and at the old ironworks at Lithgow, on the Great Western Railway, the local coal was successfully used. The coal from Rylestone is also reported to be suitable for the purpose. For the manufacture of steel of certain descriptions, supplies of manganese ore, chromite, and wolfram are available, these minerals having been found in various parts of the colony. Manganese ore is being raised near Rockley and at Glanmire, and a lode is said to occur near the Rylestone iron ore deposits. Wolfram has also been found, but not yet worked, in quartz lodes near Glen Innes and Emma-ville in the New England district.

Mr. T. W. E. David * has prepared a report on the Ironstone Mountain, Port Stephens, New South Wales. The outcrop of the ore bed has been found more or less continuously for thirty chains. The trenching proves that the bed has been thrown down by a fault to the extent of 50 feet. The average thickness of the portions of the bed which contain ore of fair quality is 3 feet 4 inches. The bed therefore contains approximately 876,000 tons of ore, containing 45 per cent. of iron. An average sample of the ore contained—

H ₂ O.	Fe ₂ O ₃ .	FeO.	Al ₂ O ₃ .	SiO ₂ .	CaO.	TiO ₂ .	CO ₂ .
3·98	52·86	7·79	5·21	18·70	1·12	7·30	1·60

* *Annual Report of the Department of Mines, New South Wales, 1892*, pp. 240-244, with plan.

The high percentage of titanite anhydride, silica, and alumina will probably preclude the bed from being worked profitably at present.

Hæmatite from New South Wales.—In a description of some New South Wales minerals, Professor A. Liversidge * describes a massive, imperfect crystal of magnetite found near Cowna Station, Barrier Ranges. Some of the faces of the crystal were well marked. Its weight was 195·303 grammes, and its specific gravity was 4·93. It possesses but slight magnetic properties, and the brown outside gives it the appearance of brown hæmatite.

A specimen of siderite obtained from vugs in the Umberumberka mine was found to be built up of plates forming cavities, in some cases almost cubical, and in others more or less rhombohedral, and varying in size from one-eighth to one inch across.

Iron Ore in South Australia.—Mr. J. B. Austin † states that about forty miles to the north-west of Port Augusta is a dome-shaped hill nearly 800 feet high, and three-quarters of a mile through the base. For two miles of its length it appears to consist solely of iron ore. Analyses of the ore show the percentage of silica to vary from 0·60 to 3·8, of metallic iron from 61·8 to 69·3, with little or no manganese in the majority of cases. Manganese minerals, however, are also met with, containing, in the examples given, from 0·47 to 1·6 per cent. of silica, 36·7 to 39·2 of iron, and 23·3 to 24·7 of manganese. The percentages of sulphur and phosphorus are not mentioned.

Mr. J. B. Austin ‡ states that a discovery has recently been made of kidney hæmatite of good quality at Leigh's Creek, South Australia. Coal and limestone exist in the immediate neighbourhood.

Native Iron in Ontario.—According to Dr. G. C. Hoffmann § there occur in the quartzite of St. Joseph Island, Lake Huron, black metallic spherulites, with an oolitic structure, of native iron. They appear to have been formed by the reduction of iron salts by organic matter. Analysis shows that this native iron, of undoubted terrestrial origin, contains the characteristic constituents of meteorites—nickel, cobalt, and phosphorus—and that these elements should no longer be regarded as characteristic of meteorites.

* *Transactions of the Royal Society of New South Wales*, 1892, pp. 234-240.

† *Mining Journal*, vol. lxii. p. 775.

‡ *Ibid.*, p. 1125.

§ *Geological and Natural History Survey of Canada*, vol. iii. p. 39; dated 1890, but published in 1892.

The Iron Ore Deposits of Torbrook, Nova Scotia.—In a paper read before the Mining Society of Nova Scotia, Mr. R. G. E. Leckie * gave a general idea of the geological features of the country surrounding Torbrook, and a rough sketch of the iron ore deposits of Annapolis and King's counties generally.

The Torbrook district is bounded on the north by a line running east and west which would mark the junction of the valley sandstones with the Devonian rocks of the South Mountain, on the east by the Vails River in King's county, on the west by the Nictau River, and on the south by a line running along the summit of the mountain and marking out the junction of the Devonian rocks with the granite. The strike of the iron ore beds runs diagonally across the oblong district thus indicated, the general direction being N. 60° E. There are four known beds of red hæmatite, which have been traced for the most part right across the whole district, a distance of six miles. No. 1 bed, the most northerly, is the most important of the four, and is the one which is being worked at the Torbrook mine. The dip is 70° to 80° S., and the bed is very regular in thickness, the average being 6 feet. The ore is perfectly clean, and non-fossiliferous. No. 2 bed lies 100 feet south of No. 1, and has been worked open-cast for many years to supply the old furnace at Nictau Falls. No. 3 bed is about three-quarters of a mile south of No. 2, and resembles No. 1 in width and structure. It may prove to be a second outcrop of No. 1. No. 4 bed is a quarter of a mile south of No. 3, and has been opened on the Messenger property, a distance of two miles east from the Torbrook mine.

Active operations at the Torbrook mine began in the spring of 1891, when steam-hoisting plant was erected and ore raised from two shafts. A four drum winding plant was put in early in 1892, and now does the hoisting for Nos. 3, 4, and 5 shafts. No. 2 shaft has a separate engine and boiler, it being intended to hoist from that shaft with steel skips of 1 ton capacity. The mine has been equipped with a compressed air-drilling plant, and there is a Cornish plunger pump in No. 2 shaft, and small steam Blake pumps in Nos. 4 and 5. The following analysis shows the average composition of the ore—

FeO.	Fe ₂ O ₃ .	MnO.	SiO ₂ .	CaO.	Al ₂ O ₃ .	MgO.
27.09	49.52	0.60	10.28	7.00	1.90	1.80

A trace of sulphur and of phosphorus was detected. The percentage of iron in the ore varies from 55.74 to 60.72. The daily

* *Canadian Mining Journal*, vol. xi. pp. 155-158.

output has increased from 20 tons in the spring of 1891, and 70 tons in that of 1892, to 130 tons at the present time.

Ore from the Bristol Mines, Quebec.—At these mines there is believed to be as much as 34,000,000 tons of iron ore available, the ore containing—

Fe.	Mn.	SiO ₂ .	P.	S.	MgO.	CaO.
63.258	0.080	7.630	0.003	0.379	3.230	2.280

The fine ore in the mine, as separated by a magnetic concentrator, is found to have the composition—

SiO ₂ .	Al ₂ O ₃ .	CaO.	MgO.	Fe ₂ O ₃ .	FeO.	P ₂ O ₅ .	CO ₂ .
1.210	0.633	0.160	1.060	65.946	30.139	0.006	0.136

The percentage of sulphur present is 0.374, and of copper 0.011.*

Iron Ore in Natal.—According to Mr. J. P. Hamilton,† there is a good deal of iron ore in various parts of Natal, and on the Prestwick farm a splendid deposit of magnetic iron ore, 3 feet 3 inches in thickness, may be traced for some distance. Within six miles large quantities of fuel are lying; but limestone is wanting in the neighbourhood, and there is no demand for the metal. The chemical composition of an average sample of the ore was found to be as follows:—

Fe ₂ O ₃ .	FeO.	H ₂ O.	Silicates.
75.70	13.63	7.68	3.00

Only a trace of phosphoric anhydride is present, so that the ore appears to be well adapted for the manufacture of steel.

An analysis of iron ore from the Dundee district gave the following results:—

Fe ₂ O ₃ .	Al ₂ O ₃ .	SiO ₂ .	H ₂ O.
82.91	12.76	3.28	1.01

No trace of phosphoric anhydride was detected in this ore. In various other places in Natal there are deposits of iron ore.

Iron Ore in Mashonaland.—Mr. R. M. W. Swan‡ reports that the quartz belts of Mashonaland contain much iron ore and some manganese. In two isolated patches of the quartzite formation at the Doroba Mountains, he found great masses of rich magnetite and hæmatite, and on the top of Mount 'Nyaguzwe, near Fort Victoria,

* *American Manufacturer*, vol. li. p. 197.

† *Transactions of the Federated Institution of Mining Engineers*, vol. lli. pp. 884-885.

‡ "The Ruined Cities of Mashonaland," by J. T. Bent. London. 1892. Appendix, p. 349.

there is also a mass of magnetite. In fact, so very abundant is iron ore, that compass bearings can rarely be taken with safety from hills in the quartz formation. Along the right bank of the Sabi river are many native villages, whose one industry is iron-smelting. They obtain the ore from Mount Wedsa, which is renowned far and wide in Kaffirland as an iron-producing mountain. Though the mineral selected is not very rich, the iron produced is very pure. The anvils used are simple blocks of hard diorite, on which the natives hammer with another smaller block.

Some Problems of the Mesabi Iron Ore.—Perhaps there is no more important and interesting question relating to the iron ores of the North-West United States than that of their origin and stratigraphical relations. In view of recent studies in the field, Mr. N. H. Winchell * reviews the elements of the problem, and shows the difficulties that lie in the way. As an introduction to the discussion he reviews the five hypotheses of the origin of the ore: (1) substitution for limestone; (2) substitution for carbonate of iron; (3) concentration of iron oxide from the decay of ferriferous schists; (4) accumulation in troughs formed by dykes cutting tilted strata at a somewhat uniform inclination; and (5) deposition from oceanic solution at the time of the formation of the rocks associated. In giving some facts of the manner of occurrence of the ore, the author points out the extent of the range and the trends of ore, the titaniferous ores being excluded from the discussion. The difficulties in the way of acceptance of any of the proposed theories may be summed up as follows:—The absence of limestone in the iron-bearing horizon; the diffusion of iron through ferriferous schists rather than concentration; the absence of dykes cutting tilted beds; the prevalence of pervious rather than impervious strata; and the evident changes in the rock of the country, whether in the forms of breccia and gravel or *in situ*. The author therefore concludes that the origin of the Mesabi ore is not satisfactorily explained by any theory yet proposed for it or for its equivalent (Gogebic) ore on the south side of the great lake. There is but one known cause acting with sufficient force, and on a geographical scale sufficiently wide, to which appeal can be made for the geographical and stratigraphical distribution of this ore, and that is oceanic sedimentation. That there has been a profound change in the sediments

* Paper read before the American Association for the Advancement of Science, August 22, 1892; *The American Geologist*, vol. x, pp. 169-179.

since their origin is evident; but whether this change took part prior to consolidation, or after it, is as yet unknown; and if after consolidation, it is equally uncertain whether it was accomplished in Taconic or in Recent time.

The Mesabi mines * are being steadily opened up, the ore delivered at the blast furnaces at Duluth assaying about 62 per cent. of iron and 0.022 of phosphorus. At the Chandler mine of the Vermillion Range 1500 men are employed, and at the opening of navigation the stock pile contained about 250,000 tons of ore. That of the Minnesota mine, where 2000 men are employed, was estimated at about 300,000 tons of ore.

The output of this range † is now certain to be at least 700,000 tons a year after the close of the present year, 400,000 of which will be from the Biwabic mine, and 150,000 from the Ohio. At this latter mine "blue" hæmatite ore, containing up to 67 per cent. of iron, has been found in quantity, and this same kind of ore has since been met with in the deeper pits of the other companies. The ore is of Bessemer quality. At the Biwabic mine the surface covering of the ore body varies from 2 to 30 feet in thickness, and below this there is an average thickness of 70 feet of ore already exposed. How thick the ore is is unknown. Some of the most northerly pits penetrated the ore at a depth of 58 feet, but nowhere else has the ore body been bottomed, though some of the pits are 115 feet in depth. As a result of the comparison of 200 assays, it is stated that the ore will average 64 per cent. of iron and 0.04 of phosphorus. No powder has been used in sinking the pits.

The Iron Ore Deposits of the Gogebic Range.—Mr. C. M. Boss, ‡ the United States Inspector of Mines for the Gogebic District, states that the developments which were made at the Colby mine led at first to the belief in the existence of two distinct veins of ore occurring throughout the Gogebic Range. Developments to the deep, however, have shown that this theory is inaccurate, the two ore bodies having joined, and the intervening horse—which was of unusual size—having come to an end. The ore mass rests on a strong dyke and pitches to the east. It is worked by pillars and stalls.

Iron Ore in Wisconsin.—A charcoal blast furnace is to be erected at Spring Valley, Wisconsin. The ore smelted will be mined in the

* *Iron Age*, vol. xlix. p. 291.

† *Ibid.*, vol. l. p. 7.

‡ *American Manufacturer*, vol. l. p. 376.

locality. It is a brown hæmatite, and the deposit is stated to be of large size. Analysis shows it to contain 50 per cent. of iron and 0.06 to 0.10 of phosphorus.*

The Clinton Iron Ore.—Pseudomorphous replacement of limestone has been widely applied to explain the formation of the iron ores of the Lake Superior region, and there has been a general acceptance of this theory for the Clinton iron ore. Mr. C. H. Smyth, jun.,† however, proposes to remove from the substitution hypothesis its original cause, and to place the Clinton hæmatites in the category of original chemical deposits of date coeval with the enclosing strata. This result he bases on a careful study of this ore at the typical locality, Clinton, New York, his conclusion being that the oolitic ores at Clinton are not of secondary origin, but were deposited as hydrated ferric oxide in intimate connection with contemporary deposition of amorphous and chalcedonic silica.

Pyrites in the Croton Magnetic Iron Ore Mines.—The late discovery of large quantities of magnetic and non-magnetic pyrites in the Croton magnetic iron ore mines is described by Mr. W. H. Hoffman.‡ During the autumn of 1891 it was found that after a blast fully 15 per cent. of the ore brought down consisted of magnetic pyrites. This was a wholly unexpected result, as previous examinations had failed to disclose the presence of sulphur-bearing ore. A second blast in November gave still more surprising results. The whole cross-section it exposed was thickly interspersed with layers of magnetic pyrites. On sampling and analysis, 155 tons of ore from this portion of the mine yielded—

Iron.	Phosphorus.	Sulphur.
45.08	0.30	23.51

and the remainder of the ore brought down contained—

Iron.	Phosphorus.	Sulphur.
33.21	0.35	6.68

No other mine in Putnam County has shown this irregularity in sulphur distribution, and the Croton deposit until late in 1889 averaged less than 3.5 per cent. of sulphur. All indications now point to an increase in sulphur. The only remedy for this difficulty is, of course,

* *Iron Age*, vol. xlix. p. 730.

† *American Journal of Science*, vol. xliii. pp. 487-496.

‡ *Transactions of the American Institution of Mining Engineers*, Plattsburgh meeting (advance proof).

more roasting, and every practicable reduction of concentrating expenses to counterbalance the extra expense of roasting. The cost of treatment in February 1892 was 13d. per ton of concentrates, and the raw ore averaged 34 per cent. of iron. It will now be necessary to reduce this item below the figure (11d.) reached in 1891, as at least 8d. must be spent on each ton of raw ore to reduce the sulphur to 0·7 per cent., the highest percentage allowable for the Bessemer process. The mines have been closed until the necessary changes in the roasting and milling plant shall have been made.

Iron Ore in New Mexico.—In the Hanover Valley, New Mexico, about fifty miles from Silver City, about 15,000,000 tons of iron ore of Bessemer quality is stated to be in sight. This iron ore field is about to be opened up, and work has already been begun. This will include the construction of a branch line of railway. Blast furnaces are also contemplated.*

Limonite in Texas.—According to Mr. R. A. F. Penrose,† limonite beds, 1 foot to 3 feet in thickness, overlying glauconite sands, occur in Cherokee, Anderson, and other counties in the east of Texas. The ore is sometimes laminated, sometimes massive or forming botryoidal masses. The origin of the laminated and massive varieties is traced to the weathering of iron pyrites, and that of the botryoidal masses to the oxidation of iron carbonate. The author gives numerous analyses, three of which are as follows:—

	Fe ₂ O ₃	Al ₂ O ₃	MnO	MgO	CaO	SO ₂	SiO ₂	K ₂ O	Na ₂ O	P ₂ O ₅	Loss	Total
I. . .	59·20	11·20	...	...	trace	...	16·20	...	...	trace	13·45	100·05
II. . .	65·79	8·31	...	trace	2·30	0·36	18·77	...	...	trace	5·05	100·58
III. . .	74·11	16·50	0·13	1·77	1·04	0·93	1·49	0·36	0·49	0·12	...	96·74

I. Massive ore, Henderson County; II. Laminated ore, north-east corner of Upshire County; III. Limonite geode from Berry Hill, Marion County.

Virginia Iron Ores.—The quantity and quality of some of the Virginian Oriskany iron ores is well known, according to Mr. E. C. Peckin,‡ who gives an account of those ore deposits, recently investigated in Craig and Alleghany counties. A section of the country near

* *Iron Age*, vol. xlix. p. 289.

† *First Annual Report of the Geological Survey of Texas*, pp. 66-83.

‡ *Engineering and Mining Journal*, vol. liv. p. 150.

Newcastle is given. The ore is found as a blanket deposit, in some places as much as 4 to 6 feet thick, sometimes overlain by 2 to 5 feet of clay. Several openings have been made, and show ore that in many instances requires no washing. One analysis shows—

Iron.	Silica.	Phosphorus.	Manganese.
49.0	6.70	0.050	0.090

Iron Ore in Mexico.—In a report * on the mining industry of the Mexican provinces of Coahuila and Nuevo Leon, it is pointed out that beds of iron ore occur near the town of Monclova in the Cerro del Mercado, at the mines of San Pedro and La Paloma, and more to the east in the Cerro del Carrizal, at the mines of Cinco de Mayo and Piedra Iman. These mines are in the possession of local and New York capitalists, but are not yet worked. The ore appears to be of good quality, as is shown by the following analytical results :—

	I.	II.	III.	IV.
Silica	0.67	11.00	3.72	3.30
Ferric oxide	74.82	59.68	86.44	83.82
Ferrous oxide . . . .	...	19.36	5.59	7.86
Alumina	0.46	0.59	0.95	0.53
Lime	8.35	6.10	0.87	0.29
Manganic oxide	4.20	0.30	0.07	0.12
Magnesia	0.24	2.09	0.40	0.38
Phosphoric anhydride .	0.05	0.25	0.03	...
Sulphuric anhydride . .	0.06	0.04	0.31	1.52
Carbonic anhydride . .	6.61	...	...	...
Combined water	3.30	0.29	2.19	1.58
Moisture	0.95	0.52	0.48	1.24
Totals	99.71	100.22	100.55	100.64
Iron	52.38	56.86	65.00	65.50

I. Cinco de Mayo ; II. Piedra Iman ; III. San Pedro ; IV. La Paloma.

The Iron Ore Deposits of Chili.—C. Vattier,† in a report addressed to the Chilian Government, states that geologically Chili may be divided into three main sections. Near the coast are granites, diorites, syenites, and similar rocks, together with mica schists and clay slates. At the back of these rocks, inland, Jurassic, Triassic, and Metamorphic rocks occur. The granitic rocks of the coast region contain the more important of the iron ore deposits. The veins are larger and more constant, and the ore richer and purer than that met with in the other districts. Manganese ore is also observed in

* *Berg- und Hüttenmännische Zeitung*, vol. li. p. 216.

† *Mémoires de la Société des Ingenieurs Civils*, vol. xlv. pp. 37-140.

this district. Amongst the known deposits of iron ore are those at Mejillones, Antifogasta, Taltal, Chañaral, Caldera, Huasco, and especially those of Totoralillo and Coquimbo, as well as those near the harbour of Los Vilos, and the one recently discovered in the south near Lebu. Copper ore, gold, and china clay also exist in this district.

The second region includes the Jurassic deposits. It lies east of the region just described, rises to a certain height up the Cordilleras and at the north, approaches the coast somewhat closely. The country in which the iron ore is found consists of limestone, marl, barytes, and gypsum.

Beds of iron and manganese ores are known near Sierra Gorda, Zuncal, and Tierra Amarilla, and in large veins iron ore is found at Tres Puntas, Atacama. Beds of manganese ore are found at various places in the province of Coquimbo, and other deposits of the two metals are met with in the province of Valparaiso, and in a portion of the province of Santiago. In this region the richest and most important silver ore deposits have been discovered.

The third district is still further to the east, and rises high up the Cordilleras to a height which is in many cases both the limit of vegetation and of ore. The country consists of conglomerates and breccias of porphyritic character, or hardened clays, sandstones, and red porphyry, metamorphic rocks, and pyroxene porphyry, mostly Liassic. In this region spathic ore occurs at Chizbla, high up in the mountains, and farther down at Challacollo both iron ore and manganese ore are met with, while titaniferous iron sand is found in the Atacama desert, near Calama, and at other places. In the province of Coquimbo iron and manganese ores are frequently met with. In the departments of Illapel and Combarbalá iron and manganese mines exist at Batuco, Lampa, Maipo, and San Felipe. Quartz and limestone are found in places in this region, as well as argentiferous lead and copper ores.

The ores of iron and manganese that have been discovered are chiefly oxides, spathic ore and franklinite being occasionally found. The ores are usually poor in both sulphur and phosphorus. Both veins and beds, as well as stockworks and other irregular deposits, occur.

The Iron Ores of Cuba.—The Cuban iron ore deposits are described by Dr. H. Wedding.* These iron ore deposits, to which frequent reference has been made in previous abstracts in this Journal,† lie in

* *Stahl und Eisen*, vol. xii. pp. 545-550.

† *Journal of the Iron and Steel Institute*, 1890, No. I. p. 198; 1892, No. I. p. 288.

the neighbourhood of the bay and town of Santiago de Cuba. The author describes the various mines, the method of mining, and the shipping arrangements. He gives the following as an average analysis of the ore :—

Fe ₂ O ₃ .	SiO ₂ .	P.	S.	Al ₂ O ₃ .	CaO.	MgO.	Mn.
91.71	5.10	0.023	0.042	0.88	0.75	0.91	0.28

The Juragua iron ore mines are situated at a distance of seventeen miles eastwards from Santiago, Cuba. All the mining is done by open workings. At one of these there is a face of ore 150 feet wide by 60 feet high, and another has a face of 100 feet by 60 feet. The total capacity is easily maintained at 60,000 tons of ore a month. Up to March 1, 1892, the shipments of ore from this deposit to the United States had reached 1,448,403 tons. The mines are but five miles from the Caribbean Sea. Some of the ore costs but 1s. 5½d. a ton to mine and load on railway waggons, and the cost of carriage to the port of shipment, La Cruz, opposite to Santiago, is 1s. 8d. a ton. The ore requires very little sorting, and on the average it contains 61 per cent. of iron. Other mines are also described.* Among those referred to are the Chauvenet, the Clarence, and the Dutilh mines. At the last-named there are loose-lying blocks of ore weighing in many instances more than three hundred tons.

The first important discovery of iron ore in Cuba was made accidentally during the cutting of a road. No attention, however, was paid to this discovery until the year 1881, but since that date the Cuban iron ore deposits have been rapidly developed. One of the groups of mines opened up is that of the Sigua Company. The ore found is very low in phosphorus, and it has been observed that the percentage of phosphorus found in the ore of this district increases gradually from the eastern to the western extremity of the range, until the Bessemer limit is almost exceeded. The Sigua ore is almost free from sulphur.

The geological characteristics of the iron ore region are as follows. Syenite is the main rock observed near the coast. It is overlain by a coralline formation, more or less broken away towards the hills, though fragments are found at an elevation of upwards of 1500 feet or more. The syenite is frequently traversed by dykes of igneous rocks, generally porphyritic. In some cases these dykes are diorite. Frequently the coralline limestone in the vicinity of the eruptive rock is found to be metamorphosed into white marble of close texture.

As is usual, the specular iron ore is found intimately associated with

* *Iron Age*, vol. xlix. p. 607.

chlorite and epidote. It is an unquestionable fact that some of the ore is a pseudomorph of the coralline rock. Some geologists, notably Dr. Kimball, have assumed that all the deposits are of this formation. It is the opinion of Mr. Graham that the latter is not the case.

West of Santiago the geology changes and the stratified rocks are encountered—notably the red sandstone as well as the limestone series of the Silurian age. No iron ore is encountered in the latter region, but numerous deposits of manganese, many of which are being worked.

It is a notable fact that the valley of the Sigua River and adjacent districts are almost entirely made up of diorite and porphyry, and this is not the case in other parts of the ore-bearing zone. This may account for the great magnitude of the Sigua iron ore deposits.

The ore deposits of the Sigua mines are numerous. Seven veins course parallel to each other, or nearly so, and within a distance of 1800 feet. Of these the Chauvenet vein measures from 40 feet in width to upwards of 74 feet, and it has been proved for a length of 1100 feet. At the Clarence mine a vein has been proved for a depth of 90 feet. An adjacent property, the Katherine, contains a vein over 300 feet in width. At present the most important deposit is, however, the Dutilh. It is practically a cliff of ore, from which, as is to be expected, many gigantic boulders have detached themselves, some of these boulders being 300 tons in weight. Standing upon the mine railroad on the 950 feet level, this cliff of solid ore can be seen to extend to an elevation of 194 feet. The same vein outcrops below the 950 feet level. The width of this vein is apparently 450 feet at its greatest extent, but it has not been actually proved on account of the difficulty in determining the exact location of the foot wall, owing to the detached masses and boulders.

Next to the Dutilh mine, and 300 feet higher up, another vein outcrops for a length of 300 yards. It is at least 50 feet in width, and probably much more, and it is proved for a depth of 400 feet. At the Arroyo Negro, on the other side of the mountain, another vein exists which shows an apparent width of 450 feet, no developments being made. The ore actually in sight, assuming a depth from the face of only 10 feet, was estimated at at least 1,260,000 tons, taking one-half the ground measured, and allowing 1 ton of rock to each ton of ore. Since then further test-pits have been sunk, and now the mine captain reports that at the Dutilh mine alone there is enough ore in sight to supply a shipment of 400,000 tons a year for the next six years. The mines are connected by a line of rail with the Port of Sigua, the rail-

way having a descending grade for the whole distance, the maximum grade being 3·4 per cent. and the maximum curve 24°. There are excellent shipping facilities, and labour is plentiful and cheap.

Microscopic Structure of Oolitic Iron Ore.—According to Bleicher,* microscopic examination shows that the oolitic iron ores of Lorraine and other districts consist of a simple or compound inorganic or organic nucleus, surrounded by regular concentric layers of a substance rich in silica and organic matter, in which microscopic grains of quartz can be recognised. The iron oxide seems to be enclosed between these concentric layers.

A Peculiar Structure in Hæmatite.—Mr. W. S. Gresley † publishes a photograph of a portion of a sample of fibrous red hæmatite of great purity from Lake Superior. The fibres run in a curved form, and the peculiarity of the specimens described is that they have holes through or running in them at different distances from one another. These cannot be holes drilled or eaten out, or burrows made by animals, nor have they been made by the hand of man. The arrangement of the structural fibres of the ore in the vicinity of the apertures is evidence against such theories. The general aspect of this singular variety of hæmatite, so strangely resembling split wood, suggests for it the name of wood iron ore. The specimen in question can in no way be regarded as pseudomorphous, or as replacing limestone, dolomite, or pyrites, nor is it mineralised wood or any fossil of a similar nature.

Studies in Structural Geology.—Mr. B. Willis ‡ gives an account of some experiments made with wax models to elucidate the geology of the Appalachian Province. These models consisted of layers of wax and other materials of different hardness subjected to a side thrust, so as to produce folding and faulting. It is shown that soft strata are thinned on the limbs and thickened on the folds of an arch, and thus an explanation may be obtained of the great local thickening of coal-beds along anticlines, and the spaces occupied by some large bodies of iron ore along similar lines of relief from pressure, as in the Lake Superior mines.

* *Comptes Rendus de l'Académie des Sciences*, vol. cxiv. pp. 590-592.

† *The American Geologist*, vol. ix. pp. 219-223.

‡ *Transactions of the American Institute of Mining Engineers*, Plattsburgh meeting, 1892 (advance proof).

Martite.—The examination by A. Lavenir* of some very fine octahedra of martite from Brazil, showed that the substance, which was soluble only in *aqua regia*, yielded, on heating to redness in a current of hydrogen, a quantity of water exactly corresponding with the formula Fe_2O_3 . The specific gravity is 5.194–5.205, whilst it should be, if the substance had been formed from iron pyrites without change of volume, two-thirds of 5. The homogeneity of the material examined appears to be evidence against a pseudomorphous origin.

A New Use for Bog Iron Ore.—According to Seger,† a firm in Aschaffenburg has brought into the market a bog iron ore containing—

Silica.	Ferrie Oxide.	Manganese Oxide.	Water.
31.15	37.48	29.36	10.40

This, mixed with a little salt, is used for imparting a black glaze to tiles and bricks.

A Natural Nickel-Iron.—W. H. Melville‡ describes a natural alloy of iron and nickel which occurs in the sand of a river in Josephine County, Oregon. Analysis shows the metallic portion to contain—

Nickel.	Iron.
23.22	60.45

The alloy is strongly magnetic, and it occurs in admixture with silicates in the form of water-worn nodules. Their origin is unknown. To this nickel-iron the author gives the name of *josephinite*.

Recent Researches on Meteorites.—According to Mr. A. E. Foote,§ three or four years ago a meteoric iron mass was ploughed up in Garrett County, Maryland. It contains over 11 per cent. of nickel and cobalt, the proportion of the latter being unusually high. It is one of the best octahedral etching irons known, being even more characteristic than most of those that have been used for printing directly on paper. Besides the octahedral structure, it also shows a large number of secondary lines regularly disposed with reference to the principal markings, similar to those described by J. Lawrence Smith in a Wisconsin meteorite in 1869, under the name of *Laphamite* markings. The original weight of the mass was 45 oz., and its present

* *Bulletin de la Société Française de Mineralogie*, vol. xii. p. 49.

† *Sprekkaal*, vol. xxv. p. 348.

‡ *American Journal of Science*, vol. xliii. pp. 509–515.

§ *Ibid.*, vol. xliii. p. 64.

weight is $36\frac{1}{2}$ oz. The paper is illustrated by photographs of the etched surface and of the entire mass.

According to Mr. G. F. Kunz,* the meteoric iron from Colfax township, Rutherford County, North Carolina, is the same as that described by L. G. Eakins from Ellenboro', Rutherford County. The mean of the following two new analyses is in good accord with that published by Eakins:—

	Fe.	Ni.	Co.	Cu.	P.	S.	Si.	Total.
I.	87.69	11.26	0.62	0.05	0.19	0.10	0.03	99.94
II.	89.22	9.37	0.53	0.04	0.19	0.08	0.01	99.44

E. Priwoznik† states that the meteorite which fell near Knyahinya in Hungary contains 5.03 per cent. of magnetic particles having the composition—

Iron.	Nickel.
82	12

Some magnetic pyrites and traces of phosphorus also occurred in this magnetic portion of the meteorite. The non-magnetic portion contained 44 per cent. of silica, and was composed of a silicate of lime, magnesia, ferrous oxide, and soda, with traces of potash and alumina. Not even a trace of manganese could be found in this meteorite.

Another meteorite, which fell near Paderborn in Westphalia, contained small metallic particles, which were found to have the percentage composition—

Fe.	Ni.	Co.	P.
92.4	7.0	0.2	0.3

No carbon could be detected. These granules were extremely malleable.

According to O. Nordenskiöld,‡ a meteorite fell in the parish of Ljungby in Scania on April 3, 1889, and was subsequently secured for the Stockholm Museum. It is a chondrite, not differing from the most usual type. Its specific gravity is 3.61, and its composition is as follows:—

Fe.	Ni.	Co.	Cu.	PbO.	Al ₂ O ₃ .	NiO.	CaO.	MgO.
14.46	1.91	0.02	0.04	13.18	2.70	0.05	1.40	23.79
K ₂ O.	Na ₂ O.	SiO ₂ .	Cr ₂ O ₃ .	C.	S.	P.	Soluble in Water.	Loss on Ignition.
0.43	1.42	36.97	0.59	0.02	2.38	0.10	0.10	0.40

* *Transactions of the New York Academy of Science*, vol. ix. pp. 197-198.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 465-468.

‡ *Jahrbuch für Mineralogie*, 1892, No. I., pp. 138-140.

The composition of the portion (nickeliferous iron) soluble in mercuric chloride was—

Fe.	Ni.	Co.	Cu.	Total.
83·67	16·24	0·17	0·34	100·42

Analysis shows that the portion soluble in hydrochloric acid consists of fairly pure olivine, whilst that insoluble in acid consists of bronzite. The various constituents are present in the meteorite in the following proportions :—

Nickeliferous iron	11·76
Olivine	40·98
Bronzite	38·86
Troilite	6·55
Iron phosphide	0·55
Chrome iron ore	0·87
Carbon and soluble salts	0·52
Total	100·09

Manganese and tin are not present. The high proportion of nickel in the nickeliferous iron is noteworthy.

The native iron found by Foote * near the Cañon Diablo in Arizona was found to contain cavities filled with a black substance containing diamonds. In other samples Mallard † finds cavities containing rounded grains of black diamond, 0·5 to 1·0 millimetre in diameter. This iron seems to be of meteoric origin. Seeing, however, that an abrupt elevation, which appears to be an extinct volcano, has been observed in the vicinity, it is not improbable that the native iron is of terrestrial and volcanic origin.

Daubrée points out that the native iron of Greenland has been shown to be of terrestrial origin, and to be connected with basaltic eruption. The determination of the origin of the native iron of the Cañon Diablo, he considers, would probably throw light on the question of the formation of diamonds.

Mr. E. E. Howell ‡ gives further particulars of the Welland, the Hamilton County, the Puquios, the De Cewsville, and the El Chañaralino meteorites. He also describes two meteorites, the Doña Inez and the Llano del Inca, found in Atacama, Chili, in 1888, during the survey of the frontier. They belong to the mesosiderite class. Pieces

* *Journal of the Iron and Steel Institute*, 1892, No. I., p. 285.

† *Comptes Rendus de l'Académie des Sciences*, vol. cxiv. pp. 812-814.

‡ *Proceedings of the Rochester Academy of Science*, vol. i. pp. 86-100; *Jahrbuch für Mineralogie*, 1892, vol. ii. pp. 33-36.

found near the Cerro de Doña Inez gave on analysis the following results:—

	SiO ₂	FeO.	Al ₂ O ₃	P ₂ O ₅	NiO.	CoO.	CaO.	MgO.	S.	Cu.	Total.
I.	18.41	58.96	6.39	0.32	5.28	0.34	3.56	4.92	1.06	trace	99.24
II.	52.87	20.96	7.52	...	0.72	trace	1.67	14.71	...	...	98.45
III.	2.94	75.84	5.89	0.46	7.33	0.48	4.42	0.53	1.54	trace	99.43

I. Analysis of the mass; II. Analysis of the portion (29.77 per cent.) insoluble in hydrochloric acid; III. Analysis of the portion (70.23 per cent.) soluble in hydrochloric acid.

The specific gravity was 3.89. Under the microscope the following constituents were detected: Red monoclinic and colourless rhombic pyroxene, anorthite, olivine, magnetite, troilite, and nickeliferous iron.

According to B. Doss,* on April 10, 1890, at 4 P.M., a meteoric stone was observed to fall on the Misshof estate in Kurland, Russia. The fall was accompanied by a loud report. The meteorite is now in the Riga Museum. Its original weight was about 5800 grammes, and its specific gravity is 3.79. It is covered by a dull black crust 0.01 to 0.02 inch in thickness, and the interior has a somewhat porous texture. It belongs to the chondrite class of meteoric stones. "Under the microscope it is seen that fragments of olivine and rhombic pyroxene are associated with particles of iron and of magnetic pyrites, and with the characteristic chondræ forming a porous mass. The metallic portion, which amounts to 23.77 per cent. of the mass, consists of 5.82 per cent. of magnetic pyrites and 17.95 per cent. of nickeliferous iron, the percentage composition of the latter being as follows:—

Fe.	Ni.	Cu.	Su.
90.75	7.52	1.06	0.67

A preliminary determination of the composition of the meteorite gave—

Nickeliferous iron	17.95
Magnetic pyrites	5.82
Silicates soluble in HCl	46.52
Silicates insoluble in HCl	29.26
Chrome iron ore	0.45
Substances soluble in water	0.12
Total	100.12

The memoir is accompanied by two plates and eight woodcuts.

Mr. G. F. Kunz and Mr. E. Weinschenk † state that on June 25,

* *Jahrbuch für Mineralogie*, 1892, No. I., pp. 71-113.

† *American Journal of Science*, vol. xliii. pp. 65-67.

1890, a meteorite was observed travelling from south to north, and the largest portion, weighing 180 lbs., fell at Farmington, Washington County, Kansas, on the farm of W. H. January, who witnessed the actual fall. The sound of the explosion was heard throughout a number of counties in Kansas and Nebraska. The approximate composition of the mass is as follows :—

	Per cent.
Nickeliferous iron	77
Troilite	5.0
Siliceous part insoluble in HCl	46.0
Siliceous part soluble in HCl	41.5

The iron gave on analysis the following results :—

Fe.	Ni.	Co.	Total.
86.76	12.18	0.83	99.77

The siliceous part yielded the following results :—

	SiO ₂ .	FeO.	Cr ₂ O ₃ .	Al ₂ O ₃ .	MnO.	NiO.	CaO.	MgO.	K ₂ O.	Na ₂ O.	Total.
I. . .	38.50	23.54	...	...	0.34	0.69	0.12	36.81	...	...	100.00
II. . .	53.80	11.98	1.41	4.32	trace	...	4.08	22.37	0.27	1.77	100.00

I. Portion soluble (olivine); II. Portion insoluble, in hydrochloric acid.

As is generally the case in stony meteorites, the nickel-iron shows a higher percentage of nickel and cobalt than is usual in meteoric irons. The meteorite belongs to the black chondrites, and has the greatest resemblance to the meteorite of Sevenkof.

According to S. M. Losanitsch,* the Jelica meteorite contains :—

	Per cent.
Metals	2.49
Troilite	7.09
Chromite	0.15
Silicates soluble in hydrochloric acid	54.00
Silicates insoluble in hydrochloric acid	36.25
Organic matter	0.12

The metals gave on analysis 66.44 per cent. of iron, 33.47 per cent. of nickel, 2.09 per cent. of cobalt, and a trace of copper.

Chrome Iron Ore in New Zealand.—In a recent report on New Zealand minerals, it is stated that chromite occurs in the Nelson district, Jackson's Bay, Milford Sound, and at Moke Creek, Otago. It is found with serpentine, particularly with the hard variety known

* *Berichte der Deutschen Chemischen Gesellschaft*, vol. xxv. pp. 876-880.

as dunite, sometimes forming 50 per cent. of the mass. In one place a 10-foot band of the ore occurs. The maximum output amounted to 3843 tons of ore in 1862, since which time the industry has practically become extinct.*

Chrome Iron Ore in California.—Chrome iron ore † from Obispo County, California, gave on analysis the following results :—

	Per cent.
Chromic oxide	52.68
Alumina	11.40
Ferric oxide	3.62
Magnesia	16.23
Ferrous oxide	11.77
Manganous oxide	0.15
Silica	3.40
Water	0.94

Manganese Ore in Wales.—In a paper on the occurrence of manganese ore near the Arenigs, Merionethshire, Mr. E. Halse ‡ notes that in the Lower Silurian formation of Eastern Merionethshire, there occur patches of trappean ash and felspathic porphyry, accompanied by manganese ore, usually in the form of psilomelane and pyrolusite. In one of the hills in the district, veins of manganese and iron ore occur. A sample of the ore gave on analysis the following results :—

Manganese.	Silica.	Phosphorus.	Iron.
46.07	14.00	0.14	1.70

From a careful examination of this and other veins, it would appear that there is no distinct evidence of these being fissure veins, the manganese ore merely locally filling the joints and certain superficial fissures in the rocks. The manganese ore has probably been derived from the felspathic ash itself.

Thinking that it would be interesting to know to what depth the manganese ore can be profitably extracted from veins, the author has reviewed the literature of the subject, and concludes that they do not go down to any great depth, probably not more than 300 feet.

Manganese Ore in the Caucasus.—Mr. J. Roberts § describes the bed of manganese ore existing at Tchiatoura, in the Caucasus. The country rock is limestone, the manganese showing as a flat eroded

* *Engineering and Mining Journal*, vol. liv. p. 393.

† *Berg- und Hüttenmännische Zeitung*, vol. li. p. 295.

‡ *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 940-952.

§ *Mining Journal*, vol. lxii. p. 990.

bed on both sides of a valley. Hitherto it has only been worked in the most primitive manner. The manganese ore deposits existing in the neighbourhood of Kvirily, on the Transcaucasian Railway, are stated to cover an area of about 84 square miles. This ore is mined at a cost varying from 2s. 6d. to 4s. per ton, the royalty is about 2s. 6d. per ton, and the cost of transport to the railway 24s. to 36s. per ton; thence to the Black Sea, 8s.; and thence to England, 12s. per ton. A railway in course of construction will considerably reduce this cost of transport.

The Covadonga Manganese District.—Mr. J. A. Jones* states that the limestone deposits of Mesozoic age occurring in the Covadonga district, Spain, contain beds of manganese ore. One such deposit to which the author refers is a secondary formation, varying from 5 to 35 yards in thickness. It consists of about equal parts of clay and manganese ore, the ore occurring in the form of boulders of pyrolusite, sometimes as much as 80 tons in weight. Several millions of tons of manganese ore exist in this deposit.

The ore as shipped to Antwerp has been found on analysis to contain—

SiO_2 .	Al_2O_3 .	Fe_2O_3 .	MnO.	CaO.	Metallic Manganese.
2.10	4.10	4.43	84.01	1.20	58.48

Of the present existing open workings, one shows a body of ore 8 yards wide and 4 yards deep, while in another the thickness of the ore is over 3 yards. One proprietor has taken out over 11,000 tons of ore from surface workings rather more than 2000 square yards in extent.†

Manganiferous Iron Ore in Sweden.—L. J. Igelström‡ describes a new locality for jacobsonite and braunite in Sweden. These two minerals are the chief ores at the Glakärn mine, in the parish of Linde. The former predominates, and occurs partly as pure masses and partly as grains disseminated through the rock-mass, which consists mainly of manganese-garnet, rhodonite, and calcite. The mineral is black, and is easily soluble in hydrochloric acid. An analysis yielded the following results:—

Ferrie Oxide.	Manganous Oxide.	Magnesia.	Insoluble.
57.65	36.74	0.72	6.02

* *Mining Journal*, vol. lxii. p. 1125.

† *Ibid.*, p. 1038.

‡ *Geologiska Föreningens Förhandlingar*, vol. xii. pp. 137-139.

Manganese Ore in Canada.—Mr. H. P. Brumell,* of the Geological Survey of Canada, describes the various important deposits of manganese in Canada. That the industry has not attained greater commercial prominence is due rather to the distance of the deposits from the market than to any insufficiency of supply. This applies, however, more especially to the low grade or blast furnace ores, rather than to the highly crystalline pyrolusite, to which the market is restricted. All the workable deposits are situated in New Brunswick and Nova Scotia. Throughout these provinces are found many comparatively large deposits of the crystalline and semi-crystalline ores, namely, pyrolusite, manganite, and psilomelane, as well as large areas of wad. The crystalline ores are, in the majority of cases, found in rocks of Lower Carboniferous age, whilst the wad deposits, being of recent formation, are found overlying rocks of any age, from pre-Cambrian upwards. The various deposits are described in detail by the author, and numerous analyses of the ores are given.

Manganese Ore from Georgia.—Mr. J. M. Couper † discusses the possibility of manufacture of ferro-manganese in the Southern United States, using the ore from the Cave Spring mines, Georgia, which contains—

Mn.	Fe ₂ O ₃ .	Al ₂ O ₃ .	BaO.	SiO ₂ .	P	CaO.
53.44	2.83	1.52	8.62	7.79	0.064	0.08

Allowing 3 tons of ore per ton of ferro-manganese, the writer shows that the manufacture would prove a profitable one. The ore is found in irregular deposits of Lower Silurian age.

Manganese Ore in Mexico.—Mr. E. Halse ‡ describes the occurrence of manganese ore near Mulegé, Lower California, Mexico. Though of no commercial value, the deposits are of some geological interest. The veins consist of psilomelane and gypsum, and course through trachytic country. No distinct evidence of any true fissure vein was obtained. The manganese ore appears to fill superficial vein-like fissures and rock joints. The ore as a rule is high in manganese (41.25 to 74.53 per cent.) and moderately low in phosphorus, silica, and iron. It may be divided physically into three classes: (1) brown, moderately hard and mixed with gypsum; (2) grey, hard,

* *The American Geologist*, vol. x. pp. 80-88.

† *American Manufacturer*, vol. li. p. 367.

‡ *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 934-939.

and crystalline; and (3) grey black, soft and friable. Numerous analyses are given, and the paper is illustrated by a map of the districts and sections of the ore-deposits.

II.—IRON ORE MINING.

The Park Hæmatite Mines.—The iron ore deposit on which are situated the Park mines of the Barrow Hæmatite Steel Company is the largest in the Furness hæmatite district, being 450 yards long by 250 yards broad, and of unknown depth. The ore has been worked since 1850, and the present output is 600,000 tons per annum. Levels are driven every ten fathoms from shafts sunk in the adjacent limestone, a lower level being driven as soon as the one above is worked out. Rises are put up from the level to the exhausted workings above, and workings are opened out in a 9-foot slice by a pillar and stall method, the next slice being worked as soon as the upper one is taken out. The roof is formed by the timber and rubbish. The timbering consists of heavy uprights 3 feet apart, with caps and brattice wood to form a close roof. Some of the timber is recovered and used over again, but a large proportion is lost. Natural ventilation is employed.*

The Iron Ore Mines of Alabama.—The iron ore mines of the Sloss Iron and Steel Company are about five miles east of Birmingham, Alabama, on the southern slope of some low hills. These hills are cut by ravines, which expose the ore and allow it to be easily worked by levels. An incline is constructed on each side of the ravine, and the tubs are lowered two at a time on a carriage, which, together with the empty tubs, is returned by a balance running on a separate track. The full tubs are discharged by tippers into waggons on two lines of railway at the bottom.

The bed is about $3\frac{1}{2}$ feet thick, dipping 18° to the south. The ore contains 55 per cent. of metallic iron. Levels, 16 feet wide, are driven 50 feet apart on a gradient of 1 in 200. Three rows of timber are put in on the lower side, leaving a roadway 7 feet wide. Upsets are driven off from each level to the next 24 yards apart; they are 6 feet wide for the first 6 feet, and are afterwards driven 10 feet in width. In mining backwards the pillars are worked longwall. There

* *Transactions of the Mining Institute of Scotland*, vol. xiv. pp. 70-72.

are 2 inches of soft slate near the roof, which is taken advantage of for holing, and the ore is then got by blasting and wedging. In one of these mines there are twenty-five levels on one side and eighteen on the other, and the production is 500 tons daily. The total cost of mining, exclusive of royalty, is 2s. 6d. per ton.*

Iron Ore Mining in China.—In a recent report to the Foreign Office, the Consul at Hankow, Mr. C. T. Gardner,† describes the progress of the works for opening up the iron ore deposits seventeen miles inland from Shih-hui-yao. At this place there is a hill of ore, some three miles long and 400 feet high. Three assays of the ore gave 55.16, 62.80, and 67.30 per cent. of metallic iron. There are evidences in the vicinity of former workings. A railroad is being built to bring the ore down to Hanyang, near Hankow, where the works are erected. Coal, though not of coking quality, is found within a short distance.

Diamond Drills.—Illustrations have been published ‡ of two forms of diamond drills for exploratory work, known as the Beauty and the Champion drills. The former is a small portable machine adapted for drilling holes $1\frac{7}{16}$ inch in diameter and extracting a $\frac{1}{8}$ -inch core to a depth of 700 feet. Its total weight is 450 lbs., but it can be divided into packages of 150 lbs., and occupies off its columns a space of 20 inches square. The second drill is a modification of a previous form known as the Little Champion drill.

An illustration has been published of an electric diamond drill made by the General Electric Company.§ The drill-head is mounted on a heavy hinge, so that it can be swung out of the way when the rods have to be hoisted, which is done by a drum mounted on the machine and also driven by electric power.

A diamond drill driven by an electric motor is also illustrated.|| Some tests made with this machine showed ample power.

Electric Rock Drill.—A new form of percussive rock drill, operated by an electric motor, has been brought out by Messrs. Roper and Tozer. In its present form it somewhat resembles the Steavenson

* *Engineering and Mining Journal*, vol. liv. p. 318.

† *Foreign Office Reports, Miscellaneous Series*, No. 247.

‡ *Engineering*, vol. liv. pp. 249, 260; *Engineering and Mining Journal*, vol. liv. p. 153.

§ *Engineering News*, vol. xxviii. p. 178.

|| *Engineering and Mining Journal*, vol. liv. p. 202.

drill, as the motor and drilling mechanism are mounted on an adjustable cross arm on a standard carried by a trolley. The drill is drawn back against a spring which delivers the blow, by means of a two-armed cam, which is driven through worm and belt gearing from the motor. The motor requires 10 amperes at 100 volts, and runs at 1800 revolutions per minute. The drill spindle runs at 115 to 120 revolutions.*

Diamond Hand-Drills in Sweden.—G. Nordenström † publishes details, due to Crälius, relating to the use of diamond hand-drills between the years 1887 and 1891. Details are given for each of these five years, and these show that during that period, which included 41,099 working days, and 8687½ shifts, the average distance bored per year was 2357·4 yards, or 1·36 yard per shift, and 0·32 yard per day's work per workman. The mean depth of each hole drilled was 89½ feet. In 1891, one such hole was drilled at Ämmeberg with these hand-drills to a depth of 84·5 yards in 66½ shifts. Another was put down during the year at Striberg to a depth of 94·5 yards. The average total cost per yard bored was £1, 10s., 30 per cent. of this being wages. Instead of hand labour, petroleum motors have been used with success, and electricity has also been employed with some advantage. The value of this method of boring will be seen from the fact that it is possible to bore to a depth of from 60 to 70 yards in twenty-five days.

System of Filling at the Minnesota Mines.—According to Mr. D. H. Bacon,‡ the iron ore deposits worked by the Minnesota Iron Company occur in lenticular masses 200 to 1000 feet long and 5 to 80 feet wide, and they stand at an angle of 70° with a vertical height of 250 to 500 feet. Some of the deposits were at first worked as open pits; but, owing to the weakness of the walls, this method had to be abandoned, as had also the plan subsequently adopted of working by underhand stoping.

The method finally adopted consists in sinking by levels of 75 feet, carrying in the cross-cuts from the shafts, and in working out the ore each way from the shaft from the foot to the hanging wall, and from 15 to 20 feet in height. When this has been done, the drifts are timbered, and loose rock is run in to the height of 2 to 5 feet above the

* *The Engineer*, vol. lxxiv. p. 302.

† *Jernkontorets Annaler*, vol. xlvii. pp. 86-98.

‡ *Transactions of the American Institute of Mining Engineers*, Lake Champion meeting (advance proof).

timber. About 10 feet of the roof is then blasted down, broken up, and thrown into the shoots, from which it is let down into trucks standing in the drift. As the stope is extended, filling is proceeded with by letting the rock in and timbering up the shoots and ladderways as before. The system is clearly shown by illustrations accompanying the paper.

By this method the expense of lowering rock is avoided, excellent ventilation is secured, and no cross-cuts are required except the one communicating with the shaft at each level. Overhand stoping is found cheaper than underhand; the roof is always near and easily examined.

Blount Springs Limestone Quarries.—The limestone quarries at Blount Springs, Alabama,* were opened four years ago, and have supplied a large amount of excellent flux for the furnaces in the Birmingham district. Analysis shows the stone to be free from magnesia and to carry 1 to 2 per cent. of silica.

The stone is worked in benches, the uppermost ones being 40 feet above the railway. Both power and hand-drills are used, the holes being put down to depths varying from 10 to 25 feet, dynamite being the explosive employed. The larger blocks thrown down are loaded on mule trucks, and tipped on to the railway waggons. So long as the quarrymen have to deal with friable and weathered material the method of working now in use is perhaps the best, but the time is rapidly approaching when underground mining will have to be taken in hand.

III.—MECHANICAL PREPARATION.

Classifying Iron Ores.—A dressing-floor for the separation of friable iron ores has been designed and described by Santesson and Larson.† Such an arrangement is now stated to have given excellent results at the Skedvika mines. It depends, in the first place, on a classification according to size, the ore being charged on to a number of superimposed and inclined classifiers, which rest on a travelling base. In this way one system of classifiers can be used for several ore

* *Engineering and Mining Journal*, vol. liv. p. 413, with illustrations.

† *Wernländska Annaler*, 1891; *Stahl und Eisen*, vol. xii. p. 761.

shoots. At Skedvika the ores are classified into three different sizes, and the classifier treats from 8000 to 10,000 tons of ore in the year.

Comminution of Iron Ores.—Mr. A. Sahlén* is of opinion that crushers and rolls are most suitable for reducing iron ores to sizes suitable for the blast furnace on account of the regularity of the size of the product, and of the cheapness of the processes. Examples of practice are given, and the efficiency of the construction of the machinery is discussed. The type of ore-breaker which has the smallest number of moving parts is the original Blake machine; but it is better to pivot the swinging jaw below the crushing face, instead of above it as in this machine, as then the points of contact between the ore and the crushing faces are most numerous below, where they are required. Besides this, the shortest stroke and greatest leverage is then at the bottom, and a more even product is produced. The speed should be as great as possible to add to the efficiency, and the swinging jaw, to be of light construction, should be of steel, cast hollow with ribs. The frame is best made of wrought metal rather than of cast steel, and the crushing faces should be of Hadfield steel.

Rolls should be driven at a high speed, 600 to 700 feet per minute being practicable. At this speed it is best to replace the levers and counterweights used in the Cornish rolls by springs. If springs, or preferably a nest of springs, are used, they should be compressed so as to practically act as a solid block till the maximum working pressure is reached, when they will give. The axles should always be parallel, and it is advisable to attach the movable journal-boxes to a pair of strong levers firmly keyed on a heavy shaft, so that excess of strain on one journal will cause both bearings to move uniformly. The crushing faces on rolls require more attention than on ore-breakers, as the exact parallelism is of the highest importance. Chilled iron faces are being replaced by rolled or hammered steel tires, which should be in one breadth, as they can be rolled 16 inches in width by modern machinery. Belt gearing is preferable to toothed gearing for driving the rolls, on account of the smaller wear and the give, and it is allowable to apply more power to the fixed roll as long as slip of the material between the rolls is avoided. In the feed regulator it is advisable to contrive some arrangement by means of adjustable scrapers in order to regulate the flow of ore at any given point of the face of the rolls, as this is the most efficient method of keeping the tires true.

* *Transactions of the American Institute of Mining Engineers, Lake Champlain meeting (advance proof).*

Conveyor belts travelling on concave rollers are preferable to screw or link chain elevators, as the wear in the latter is great. Belts with buckets riveted on may be used if indispensable. The screens should be interchangeable with the minimum of trouble, and should be reversible, as wear is greatest on the inner side. According to the author, the best form is a hexagonal prismatic frame fitted with perforated steel plates having diagonal slots; the plates can be removed without disturbing the centre, and can be reversed. The time that the ore remains in the screen can be controlled by varying the pitch of the shaft.

In the discussion on Mr. Hoffman's papers * on crushing iron ores for magnetic separation, Mr. S. R. Krom † urges several objections to the claims of the Sturtevant mill as the most suitable and economical machine for the purpose. Besides the additional considerations of increased wear and power due to the process of attrition, and to the high speed necessarily maintained, Mr. Krom shows that grinding by attrition produces more dust than crushing with a system of rolls. Tests as to the relative quantity of dust produced by a 20-inch Sturtevant mill, and by rolls from the same ore (Port Henry, New York), gave the following results:—

	Sturtevant Mill.	Rolls.
	Per cent.	Per cent.
From 10-mesh to 100-mesh, granular	86½	96½
Through 100-mesh, dust	13¾	3¾

Ground or crushed to pass a 16-mesh screen, the samples gave:—

	Sturtevant Mill.	Rolls.
	Per cent.	Per cent.
From 16-mesh to 100-mesh, granular	82½	93¾
Through 100-mesh	17½	

A 10-mesh screen has holes $\frac{1}{8}$ inch in diameter, and a 16-mesh screen has holes $\frac{1}{16}$ inch in diameter. Notwithstanding the probable diminution by the use of an exhaust fan of the dust remaining in the sample of ore as received after treatment in the Sturtevant mill, the excess of that constituent in the mass is clear from the figures given above.

Mr. Sahlin ‡ having in his paper on magnetic concentration advocated the use of Hadfield steel, Mr. E. C. Huxley § in the discussion

* *Journal of the Iron and Steel Institute*, 1892, No. I., p. 304.

† *Transactions of the American Institute of Mining Engineers*, Lake Champlain meeting (advance proof).

‡ *Journal of the Iron and Steel Institute*, 1892, No. I., p. 303.

§ *Transactions of the American Institute of Mining Engineers*, Lake Champlain meeting (advance proof).

pointed out that he has not found this steel to wear so well for bushings on the Sturtevant mill as chilled iron. Mr. H. M. Howe noted that these bushings were not of manganese steel at all, and he deprecated the practice of calling manganese steel "Hadfield steel." Manganese steel is a special steel of very unusual properties, and for that reason, while highly desirable for certain specific purposes, is applicable only within a comparatively limited sphere. The great value of manganese steel is its power of resisting combined shock and abrasion. In neither hardness nor toughness alone does it excel other steels, but in the combination of these qualities. This combination renders it applicable to the Cyclone pulveriser, in which abrasion and violent blows from lumps of ore have to be resisted. These same conditions, however, do not obtain in the Sturtevant mill, in which abrasion alone is to be resisted.

The Magnetic Separation of Iron Ore.—At the Sanford ore-bed, Moriah, Essex County, New York,* Mr. W. P. Blake† erected in 1852 a magnetic machine for the removal of iron ore from the so-called red sand, a granular form of apatite. The machine weighed 1400 lbs., and the cost was £240. It was constructed not with permanent magnets, but with electro-magnets. It was first turned by hand, and twelve battery-cells were used. The magnets not being sufficiently strong, more batteries were procured, and the machine was driven by steam-power. The ore was dried in kilns, then ground and fed upon a leather belt, which carried it under the magnets. After experiments had been made for three months, the machine worked fairly well, using twenty-four cells, and giving a product of from 3 to 5 tons a day of granular phosphate. The original material contained 20 per cent. of iron ore. At one time thirty-six cells were used. The strength of the magnets was unequal, the belt was uneven in its tension, and a brush was necessary to secure complete delivery of the iron ore. The agitation of the mixed ore was found to be important, as the separation was more thorough when the charge was stirred.

The results recently obtained in America in the magnetic concentration of iron ore are fully dealt with by A. Sjögren.‡

In a paper read before the Institution of Mining and Metallurgy, Mr. W. B. Basset§ described the various machines which have been

* *Journal of the Iron and Steel Institute*, 1892, No. I., p. 282.

† *Transactions of the American Institute of Mining Engineers*, Lake Champlain meeting (advance proof).

‡ *Jernkontorets Annaler*, vol. xlv. pp. 49-77.

§ *Mining Journal*, vol. lxii. p. 1187.

devised for the magnetic separation of ferruginous material. The first machine appears to have been made in 1850 by Ommanly and Tatham. In this two parallel endless chains working over rollers carry a number of transverse metal bars, to which are affixed permanent horse-shoe magnets, from which the magnetic material is afterwards removed by a brush. In Cook's machine the ore fell on a belt revolving over a magnetic wheel, the passage of the belt outside the magnetic field removing the magnetically separated material. The Sauttée Harlé separator is a similar arrangement. That of Hoffman, in use at the Croton mines, has been frequently referred to in the *Journal of the Iron and Steel Institute*. In the Faber arrangement permanent magnets form a drum, a scraper being used to separate the material removed by the magnets. A similar magnetic drum, with slightly altered hopper-charging arrangements, formed the machine devised by Fisher. The well-known Edison machine is also a drum with scraper arrangements, a current of water being used to carry the ore within the range of action of the magnetic wheel or drum. Machines of somewhat similar arrangement, which the author refers to in more detail, are those of Bell and Basset, Buchanan and Fiske. In the Alexander machine a containing vessel filled with water is caused to revolve, and magnets are suspended in this with their poles downwards. The ore being charged, the magnets gradually increase in weight by the material attaching itself to them, finally drop, and break the circuit. The magnetic material falls from them, and the magnets rise again into position.

The introduction and development of the magnetic separation of iron ore is fully treated by Mr. A. Sahlin.* He commences with a discussion of the importance and use of concentrates, and then deals with the preparation of the ore, including the various arrangements of crushing machinery, and the methods of separation.

Mr. H. L. Chase † describes a magnetic ore separator he has devised. Its two chief features are the smallness of the magnetic wheels and the peculiar structure of the magnets; and, secondly, the fact that it can be worked when immersed in water, whereby not only is the dust allayed and the ore washed, but also the weight to be borne on the lower side of the belt is decreased. The machine, as is shown by the drawings accompanying the author's paper, belongs to that class in

* *Engineering and Mining Journal*, vol. lili. pp. 616-617, 636-641, 662-664.

† *Transactions of the American Institute of Mining Engineers*, Lake Champlain meeting (advance proof).

which the material is separated into three classes—tailings, middlings, and heads. The material is fed from a hopper on to a horizontal belt which passes round the first magnetic wheel. As the material passes downwards the tailings fall off into their tank, and the middlings fall into the next division, when the material comes opposite a row of fixed magnets above the belt. The pure magnetite is carried round the second magnetic wheel, and as it ascends it leaves the belt and is attracted by a third magnetic wheel to the belt which passes round it. Up this belt the ore is carried, and delivered over a pulley into a receptacle outside the tank.

The magnetic wheels are each made of a soft iron roll of small diameter (4 inches) and 3 feet in length. In each of two spiral grooves cut in the circumference of the wheels there is a coil of copper wire, and the electric current in one goes in the opposite direction to the other. The magnetic field thus obtained is very strong. The band is made of cotton duck, and it is found to endure the blows of the sharp material by yielding before it, just as wax does before a sand-blast.

A supplementary paper on magnetic concentration at the Tilly Foster mine has been prepared by Mr. F. H. McDowell.* During 1891 the circumstances under which the magnetic separator worked at this mine were rendered much more disadvantageous than in 1890, and yet the cost per ton of concentrates has been reduced from 8s. 5d. in 1890 to 7s. 11d. in 1891. The difficulties were due to three causes. The richer portion of the ore heap became exhausted, the accumulated tailings had to be removed from the vicinity of the mill, and a prolonged drought exhausted the reservoir from which the water supply was derived. These difficulties were overcome in an ingenious manner. The water was obtained from a small stream, and by means of a pumping back system a daily flow of 12,000 gallons was made to do duty for 240,000 gallons, the amount required at the mill in ten hours.

According to Nordenström,† magnetic separation has been introduced at Stora Slotterberg, Tuna Hästberg, Dannemora, and Mattegrube. At Slotterberg the ore heap consisted of about 60,000 tons of magnetite, assaying 60 per cent. of iron. Since 1885 a Wenström separator has been in use. To serve it eight men and five boys are employed. The output is about 2·7 tons of separated ore

* *Transactions of the American Institute of Mining Engineers*, Lake Champlain meeting [advance proof].

† *Jernkontorets Annaler*, vol. xlv, pp. 99-113.

per hour, at a cost of 17d. for labour, and 4½d. for other charges. At Tuna Hästberg, 24,120 tons of stuff have been treated. This contained 16·2 per cent. of ore. The magnetic separation cost 3s. 1½d. per ton of ore produced. At Dannemora, 50 tons of mine smalls are treated in eight hours, about 4d. per ton being paid for the separated ore, so that the process is five times as cheap as the original hand separation.

At the Monteponi mines in Sardinia a product is obtained which consists of a mixed ore of zinc and iron. This cannot be separated by wet methods, and in consequence magnetic separation has been introduced. E. Ferraris* describes this plant. The magnetic separator is a segmental drum divided into two halves, separated by neutral zones. When the segments pass through these zones the iron ore attached to them falls off into a collector.

IV.—METALLURGICAL PREPARATION.

Roasting Iron Ore in Canada.—In a paper read before the Mining Society of Nova Scotia, Mr. R. G. Leckie† gave a description of the roasting-kilns at the Londonderry ironworks. The kilns are a modification of the gas roasting-kiln introduced by Westmann in Sweden. The total height of the kiln from floor to charging-door is 28 feet, the diameter at the top is 13 feet, and 18 feet at the base. In the centre is a circular brick flue 36 inches in diameter. This opens at the top into the chimney, and assists in drawing the gases and the products of combustion laterally through the ore by twelve ports 12 inches by 2½ inches, situated a little above the line of gas ports. The gas ports are sixteen in number, and in front measure 10 inches by 8 inches, but flare back, so that in the interior there is but a point of fire-brick 3 inches wide separating them. This is divided by a fire-brick partition, so as to give a more uniform distribution of gas and flame. The gas is admitted by a double opening in the bottom of the port, covered by a loose plate of cast iron, which can readily be moved so as to regulate the admission of gas. Formerly the gas was made in producers, but now waste gas from the blast furnace is brought over in wrought-iron pipes 18 inches in diameter, and distributed around

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 234-235, with plate.

† *Canadian Mining Review*, vol. xi. pp. 154-155.

the kiln by a cast-iron pipe, containing openings for cleaning and moving the dust carried over in the gas current.

The raw ore when charged in the kiln contains on an average per cent. of iron, and when thoroughly calcined 33 per cent. Under normal conditions each kiln can treat daily (twenty-four hours) 60 tons of raw ore, but over 80 tons have been calcined when good gas was available. Two men are employed per shift on each kiln, one standing on the platform and one attending to the gas and drawing the ore. The ore is wheeled direct to the weighing machine, and then charged into the furnace whilst still hot.

REFRACTORY MATERIALS.

Fireclay from Eckersdorf.—H. Seger and E. Cramer* have examined fourteen samples of burnt clay-slate from the Ruben mine at Neurode. The substance occurs as a bed, at the base of seven coal-seams, with a thickness of 2 to 4 yards, a dip of 23°, and a length in the direction of the strike of 1500 yards. It has been explored to a depth of 204 yards. The colour of the calcined material is nearly white, and the proportion of ferric oxide, lime, magnesia, and alkalis, as shown by the analyses given by the authors, is extremely small. The material is extremely refractory, and in this respect resembles the well-known Rakonitz fireclay.

Groden Fireclay.—An analysis of Groden fireclay by H. Seger † gave the following results:—

SiO ₂ .	Al ₂ O ₃ .	Fe ₂ O ₃ .	CaO.	MgO.	Alkalies.	H ₂ O.	Total.
49.90	34.99	1.20	0.50	0.38	2.02	11.28	100.27

The clay is very plastic, and its degree of fusibility is represented by No. 34 of Seger's scale.

Fireclay from Wildstein.—This German fireclay is stated by Bischof ‡ to contain—

SiO ₂ .	Al ₂ O ₃ .	Fe ₂ O ₃ .	CaO.	MgO.	K ₂ O+Na ₂ O.	Loss.
50.03	34.41	1.06	0.33	0.18	2.78	11.46

Notwithstanding the high percentage of the alkalis, this clay is stated to be very refractory.

Fireclay from New South Wales.—Mr. J. C. H. Mingay§ gives the following results of analyses of white clays furnished with

* *Thonindustrie Zeitung*, vol. xvi. p. 675.

† *Ibid.*, p. 559.

‡ *Sprechsaal*, vol. xxv. p. 193.

§ *Annual Report of the Department of Mines, New South Wales, 1892*, pp. 277-278.

a view of ascertaining their suitability for the manufacture of firebricks :—

	H ₂ O.	Fe ₂ O ₃ .	SiO ₂ .	Al ₂ O ₃ .	CaO.	MgO.	K ₂ O, Na ₂ O.	Total.
I. . .	6.07	0.05	77.11	14.26	0.25	0.71	1.55	100.00
II. . .	8.21	1.02	73.35	14.23	trace	0.65	2.09	99.55
III. . .	10.04	2.04	65.13	22.05	trace	trace	0.74	100.00

The first sample was of no value for the manufacture of firebricks. The second and third samples, like a large number of other fireclays from New South Wales, which have come under the author's notice during the last few years, have proved themselves from experiments made to be of excellent quality for the manufacture of firebricks.

In a subsequent report,* Mr. Mingaye gives the following results of an analysis of a firebrick made from clay obtained in the neighbourhood of Sydney :—

SiO ₂ .	Al ₂ O ₃ .	K ₂ O.	Na ₂ O.
89.45	10.40	0.32	0.36

with traces of ferric oxide, lime, magnesia, titanio acid, and vanadium.

Bauxite from the Vogelsberg.—By a careful study of microscopical sections, Dr. A. Liebrich† has obtained evidence that the bauxite of the Vogelsberg possesses a perfect basaltic structure, and is therefore the product of the alteration of a basaltic rock. On analysis, this bauxite proves to be a partly amorphous, partly crystalline aluminium hydrate, rendered impure by the addition of ferric oxide, some titaniferous iron ore, and silicates.

Fire-Resisting Sand.—A very fine-grained sand, which has a fire-resistance between Nos. 31 and 32 of the Seger scale, scarcely clotting together or contracting even at very high temperatures, is found near Cobern-Gondorf, on the Moselle.‡ It is slightly mixed with clay, and yields on analysis the following results :—

SiO ₂ .	Al ₂ O ₃ .	Fe ₂ O ₃ .	K ₂ O	Loss.
93.13	4.30	0.29	0.74	1.55

Ceylon Graphite.—Mr. J. Ferguson§ describes the mineral resources of Ceylon. The output of graphite has rapidly increased in

* *Annual Report of the Department of Mines, New South Wales*, 1892, p. 279.

† *Beitrag zur Kenntniss des Bauxits vom Vogelsberge*, Giessen, 1892.

‡ *Thonindustrie Zeitung*, vol. xvi. p. 286.

§ *Mining Journal*, vol. lxii. p. 703.

recent years. In 1880 the quantity exported amounted to 10,287 tons, while in 1891 this quantity had increased to 20,013 tons, valued at 4,002,680 rupees. Analysis of Ceylon graphite has shown the following results:—

Variety.	Specific Gravity.	Volatile Matter.	Carbon.	Ash.
		Per cent.	Per cent.	Per cent.
Columnar	2.2671	0.158	99.792	0.050
Foliated	2.2664	0.108	99.679	0.213

A specimen of the columnar variety, examined by Dr. E. J. Ball in the metallurgical laboratory of the Royal College of Science, showed 0.04 per cent. of ash.

The Preparation of Graphite.—The action of nitric acid on graphite, to which H. Luzi * has drawn attention, is stated to be of considerable practical importance. The mechanical preparation of graphite is not perfectly satisfactory in its results, and the Brodir method has also its disadvantages, in that it leaves a graphite containing hydrogen and oxygen and resembling lamp black rather than graphite. Luzi † moistens the graphite with concentrated nitric acid, and then ignites immediately. A number of fibres then form on the graphite, which largely increases in volume. These fibres are chemically unchanged graphite, and are so light that they float on water, whilst the inorganic constituents liberated by this change of volume sink to the bottom. The nitric acid can be re-collected.

The Manufacture of Magnesia Bricks.—P. Karnasch ‡ manufactures magnesia bricks by burning a compressed mixture of burnt magnesite and blast furnace slag, using ninety-five parts of the former to four of the latter, and one part of common salt.

The Stephenson and York Chequer Brick.—This is a new form of fire-brick for use in hot-blast stoves or in regenerative chambers. The shape of the brick is that of a double Latin cross, the head and arms being of the same length, whilst the body or distance between the two arms is twice that length. The brick intended for hot-blast stoves has square edges and a flat top, whilst that intended for regenerators has a bevelled top to prevent the deposition of dust. §

* *Journal of the Iron and Steel Institute*, 1892, No. I., p. 306.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. p. 462.

‡ *Chemiker Zeitung*, vol. xvi. p. 799.

§ *Iron Age*, vol. xlix. p. 768, with nine illustrations.

FUEL.

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I.—CALORIFIC VALUE.

The Calorific Power of Fuels.—An extended study of the calorific power of combustibles used for industrial purposes has been published by P. Mahler,* and is reported upon by A. Carnot and H. le Chatelier. The author has used his modification † of Berthelot's bomb, and a full description is given of the apparatus and of the method of using it. For solid materials a gramme of the substance is placed on the support, connected to a fine spiral of iron wire, which can be heated by an electric current. The shell is closed, and oxygen is admitted from a bottle till the pressure reaches 20 to 25 atmospheres. The temperature is taken every minute for several minutes, both before and after the combustion, which is practically instantaneous. By this means the maximum temperature and the rate of loss by cooling are ascertained, and the corrections for loss of heat can be made with great exactitude. Examples are given of several determinations to show the methods of calculation. After the experiment the vessel is opened, and the acid produced is washed out and titrated. A little water is placed in the shell if the combustible does not contain sufficient hydrogen to form the acid. Besides coal, any powdered solid or liquid combustible can be tested in this manner, unless it is volatile, in which case it is enclosed in a glass bulb and connected to the spiral.

* *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 4th series, vol. vii. pp. 317-374.

† *Journal of the Iron and Steel Institute*, 1892, No. I., p. 308.

For testing a gas the capacity of the shell is first gauged, and it is then filled with the gas, exhausted, and again filled. Oxygen is passed in until a pressure of $\frac{1}{2}$ to 5 atmospheres, as measured by a mercury manometer, is reached. The lower pressure is used for gas such as that obtained from a Siemens producer, and the higher pressure for illuminating gas. The water equivalent of the shell and its accessories is calculated from the specific heats and weights of the component parts, and is checked by burning naphthalene. The agreement between different experiments with this substance and with the calculated results is very close.

A very large number of experiments have been made with this apparatus. These are set out in tabular form, showing the chemical composition of the combustible, both solid, liquid, and gaseous, and the calorific value as determined by experiment, and in many instances by calculation also. The bearing of the experiments on the calculated results is also discussed.

Berthelot* also describes the method of using this apparatus for solid, liquid, and gaseous combustibles with reference to the pressure of oxygen to be used in the vessel.

Scheurer-Kestner† quotes further examples to show that the actual heating-power of coal cannot accurately be calculated from its percentage composition by means of Dulong's formula, the possible error being as much as 12 per cent.

Berthier's method of assay gives results which differ widely from those obtained with the calorimetric bomb.

The Heat Absorbed in Distilling Coal.—H. von Jüptner,‡ referring to coal from the Commentry district, gives a table showing the calorific powers of the various products obtained, and from the calorific power of the coal itself, calculates the heat which was absorbed in producing chemical change during the distillation of the coal. Thus 100 kilogrammes of the coal referred to gives 42,060 calories, while the coke and all the other products of the distillation yield but 15,830 calories.

The Determination of High Temperatures.—E. Blass§ describes a lengthy series of investigations made with a view to determine

* *Comptes Rendus de l'Académie des Sciences*, vol. cxv. pp. 201-203.

† *Ibid.*, vol. cxiv. pp. 1269-1272.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. p. 436.

§ *Stahl und Eisen*, vol. xii. pp. 893-909.

the accuracy of the theory of Le Chatelier in the case of the combustion of water-gas, both when using an excess of air or an excess of water-gas. In the first place, the author had to take into consideration the accuracy of the various pyrometers. He found a Wiborgh air-pyrometer gave very concordant results with that of Braun and Hartmann. The main difficulty connected with the use of the latter is that much noise renders very difficult an accurate listening to the vibrations of the telephone used for the temperature determination. The Chatelier pyrometer is a handy instrument, but the thermo-couple varies in sensitiveness, and the mirror is unsteady in the neighbourhood of machinery in motion. The Decretel telescope is only useful for comparative purposes, but alloys gave better results.

The author describes in detail the experiments as well as the calculation of results, and he shows that in practice the theory of Le Chatelier may be taken as absolutely accurate: that not only the specific heat of carbonic anhydride, but also that of water vapour, increases rapidly with the temperature, the mean specific heat being—

For carbonic anhydride, $0.188 + 0.000273t - 0.0000000537t^2$.

For water vapour, $0.420 + 0.000364t$.

These calculations allow for water-gas and air, both burnt cold, a maximum temperature of 1710° . A temperature of 1690° was observed in one experiment.

Several instruments for measuring high temperatures are described by Professor W. C. Roberts-Austen.* Those mostly used at the present day depend on the measurement by the aid of electricity or by optical methods. Several electrical pyrometers are in use, but they are as a general rule too costly, and are not sufficiently simple for everyday use in works. A full description is given of Le Chatelier's new optical pyrometer, which is based on the photometer of Cornu, and of some experimental determinations by its aid. The author deals with the question of pyrometry from the point of view of the special needs of the engineer.

Dr. L. Holborn and Dr. W. Wein† have made an elaborate series of comparative tests with the Le Chatelier pyrometer and the air-pyrometer. Experiments were made with thermo-elements containing not 10 per cent. of rhodium, as prescribed by Le Chatelier, but 9, 11, 20, 30, and 40 per cent. It was found that the thermo-electric force for high temperatures largely increased with the proportion of

* *Minutes of Proceedings of the Institution of Civil Engineers*, vol. cx. pp. 152-166.

† *Zeitschrift für Instrumentenkunde*, vol. xii. pp. 257-267, 296-307.

rhodium, whilst at lower temperatures the difference was less distinct. The increase of the thermo-electric force with the percentage of rhodium is fairly uniform from 10 per cent. upwards, so that for the preparation of an element of constant action no special alloy is to be preferred.

Messrs. Braun and Hartmann* have devised a pyrometer which, in principle, is a modification of the Siemens pyrometer. As in this latter a platinum spiral is placed inside a protecting iron tube. The variations in the resistance of this spiral, due to differences in temperature, are observed by the aid of a galvanometer; except in cases where the instrument is likely to be subjected to much vibration, the galvanometer is replaced by a telephone.

II.—COAL.

The Microscopic Examination of Coal.—J. Wiesner† states that the chief constituent of lignite is a substance which is brown, transparent, and is decolorised by chromic acid, leaving a residue which shows the reactions of cellulose. As, however, this does not withstand the action of chromic acid, it follows that lignite is completely decomposed by chromic acid, or rather by the mixture of potassium bichromate and sulphuric acid, which the author employed. The other kinds of fuel which were examined ranged from anthracite through coking coal to charcoal, lampblack, and graphite. These all contained some of this substance, destructible in chromic acid, which was observed in lignite, though usually in very small quantities. Examined under the microscope in the form of a fine powder, the chromic acid solution in contact with the fuel becomes in the first place brown and finally green. The residue, even after having been treated for some weeks with fresh solution, shows no sign of any change. It behaves like amorphous carbon, and at the ordinary temperature is only attacked by chromic acid with extreme slowness. Anthracite consists in the main of a black material scarcely at all affected by a chromic acid solution. It also contains a transparent, deep-brown coloured substance, which is slowly oxidised by chromic acid, but leaves no cellulose residue. Bituminous coal appears to be a mixture of lignite and anthracite, leaving a small quantity of cellulose

* *Stahl und Eisen*, vol. xii. pp. 656-657, three illustrations.

† *Monatshefte für Chemie*, vol. xiii. pp. 371-410.

after the chromic acid treatment. Brown charcoal is completely decomposed by chromic acid, cellulose being readily observable. Black charcoal, on the other hand, is scarcely attacked.

The Soluble and Resinoid Constituents of Coals.—In continuation of their previous researches* on the soluble and resinoid constituents of coals, Professor W. Smith and Mr. J. C. Chorley † have examined further samples of coal from the island of Kiushiu, Japan, whence the Miike coal was obtained. The analyses of the coal and ash show that the bituminous matter increases with the lime, and the more recent coal contains most. This seems to prove that these substances are not secondary products, but are the original resins produced by vegetation, which have not had so much opportunity of being altered.

Composition of Coal.—Professor R. Åckerman ‡ gives a table showing the relative weights and compositions of coals used in Sweden. The coals are derived chiefly from collieries in South Yorkshire. The mean of the results given is as follows:—

	Kilogrammes.
Weight of coal per cubic metre, as used	746
" " as dried	723

On heating in a closed crucible, the coal yielded—

Hygroscopic water	3.2
Gases, incombustible	6.3
Gases, combustible	18.7
Carbon	66.0
Ash	5.8
Total	100.0

The composition of the dried coal was—

Carbon	77.3
Hydrogen	5.2
Oxygen	9.9
Nitrogen	1.2
Sulphur	0.4
Ash	6.0
Total	100.0

* *Journal of the Iron and Steel Institute*, 1892, No. I., p. 313.

† *Journal of the Society of Chemical Industry*, vol. xi. pp. 591-592.

‡ *Jernkontorets Annaler*, vol. xlv, pp. 321-462.

The percentage of elements combined with 100 parts by weight of carbon was—

Carbon	100.0
Hydrogen	6.8
Oxygen	12.8
Nitrogen	1.6

One cubic metre of coal contains—

	Kilogrammes.
Carbon	558.2
Disposable hydrogen	28.3
Hygroscopic water	23.9

The Spontaneous Combustion of Coal.—O. Binder * has devised an arrangement for the determination of the temperature existing within a large mass of coal. An iron tube is thrust into the coal to be examined, filled with oil, and a thermometer inserted. By using a number of such tubes the average temperature of the mass can be ascertained. As a means of judging as to the probability of the spontaneous combustion of the coal, a determination of the moisture it contains is suggested, as from the quantity of moisture which the dry coal will absorb from the atmosphere, the capacity for absorption of a given coal can be judged. The following table is given to show the applicability of this method :—

Chance of Spontaneous Combustion.	Percentage of Pyrites.	Percentage of Moisture.
Very slight	1.13	2.54
	1.01-3.04	2.75
	1.51	3.90
Average	1.20	4.50
	1.08	4.35
	1.15	4.75
	1.12	4.85
Large	0.83	5.30
	0.84	5.52
	1.00	9.01

The causes of spontaneous combustion of coal, and the prevention of explosions on shipboard, are also dealt with by Mr. M. V. Jones,† especial attention being paid to the ventilation. In the discussion, it was noted by Mr. A. L. Stevenson that coal-bunkers at coke-works often took fire unless they were frequently emptied and cleaned out.

* *Stahl und Eisen*, vol. xii. p. 809.

† *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 789-794.

Geology of the Northumberland and Durham Coalfield—

The geological features of this coalfield are perhaps better known than those of any other in Great Britain. A careful summary of what is known of the geology of this coalfield has been prepared by Mr. C. J. Murton,* and his paper is illustrated by a geological map of the district, a general vertical section of the strata, and a cross section across the Team Wash, near its junction with the river Tyne. As an example of denudation the Team Wash is of interest. It once formed a valley fifteen miles in width, and is now filled up with sand, gravel, and clay. It has denuded the strata for a depth of 300 feet in some places.

The chief value of the limestone beds below the coal is their use as a flux in the manufacture of pig iron in the Cleveland district. An average analysis of the mountain limestone shows 96 per cent. of calcium carbonate, 1 per cent. of magnesia, 1 per cent. of ferric oxide and alumina, and 2 per cent. insoluble in hydrochloric acid.

The coalfield does not contain many distinct varieties of coal, the product being almost invariably bituminous. Physical characters rather than chemical composition determine the economic value of the coals. Analyses of several varieties gave the following results:—

	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Sulphur.	Ash.
I.	85.58	5.31	1.26	4.39	1.32	2.10
II.	82.05	4.78	1.02	9.32	0.78	2.05
III.	83.47	6.68	1.42	8.17	0.60	0.20
IV.	88.26	4.66	1.45	0.60	1.77	3.26

I. Coking coal, Hutton seam; II. Steam coal, Low Main seam; III. Household coal, Hutton seam; IV. Semi-anthracite, South Wales.

Geology of the Resicza-Domán Coalfield. — G. von Bene† describes the Liassic coal-seams, which have been worked since 1855, in the Hungarian county of Krassó-Szörény, the product being a coal specially adapted for blast furnace use. The upper seam is 1 to 2 yards in thickness. The lower one is extremely variable in thickness, being 2½ feet at the Leopold shaft where it is not worked, and as much as 9 yards at the Szóczen workings. The usual thickness is 2 to 3 yards.

In the Doman colliery, two varieties of iron ore occur, one a pyritic

* *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 620-631.

† *Földtani Közlöny*, vol. xxi. pp. 289-300.

blackband ore found above the upper seam, the other a bluish grey ore occurring in lenticular masses, and giving on analysis the following results :—

Fe.	SiO ₂ .	Al ₂ O ₃ .	CaO.	MgO.	P.	Loss on Ignition.
37.62	10.60	4.50	0.90	0.65	0.08	27.40

This ore is extremely rare, having been hitherto met with in only two localities.

Coal in Croatia.—According to R. Helmhacker,* coal-seams occur from South Styria through Croatia along the whole length of the mountain range. They are known at Gonobic and Studenic in South Styria, and in Croatia at Petrovsko, Krapina, Jesenje-gornje, Radoboj, Vetrnica, Golubovec, Ivanec, Beletinec, Koprivnica, and other localities in the Belovar range. The lack of means of transport has prevented the development of the mining industry. The coal-seams of the western portion of the range, where the Triassic limestone crops out, are black lignites of excellent quality. The deposit at Beletinec is of importance on account of the railway to Agram, which passes in the vicinity. Five seams are known, the coal in each case being of good quality, and containing no partings and but little pyrites. The uppermost seam is 4 feet in thickness, and the second is 6 feet. The other three seams average 4 feet, but are only known at their outcrops. The first two seams have been opened by means of adit-levels, and found to be of constant thickness. The discovery of seams of coal of good quality in the vicinity of the railway is full of promise for the establishment of a Croatian mining industry. The author's paper contains a full account of the geological structure of the district.

The Buschtiehrad Coal Deposit.—The seam of coal which cropped out along what is now the line of the railway from Kralup to Wejhybka was discovered in the year 1775. Its discovery has led to the opening up of the important coalfield of the Buschtiehrad-Kladno district, Austria. A historical account is given of the mode of discovery of this coal-seam, and of its working down to modern times.†

Coal in the South of France.—M. Olivier gives some notes by M. Nagel ‡ on the search for coal at Gagnières and the discoveries of

* *Berg- und Hüttenmännische Zeitung*, vol. li. pp. 358-359.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 419-423, and 437-439.

‡ *Société de l'Industrie Minière, Comptes Rendus Mensuels*, 1892, pp. 81-90, with five plates.

the Mokta-el-Hadid Company. After a reference to the geological discussions which have taken place over the Gard coalfield, the author describes the plant used in deepening the shaft and in driving exploratory roads and inclines, with details of the cost. The seams found were as follows:—

Number.	Depth	Thickness.	Ash.	Volatile Matter.
	Yards.	Feet.	Per cent.	Per cent.
1	542	4.1	7	14
2	560	2.4	20	12
3	567	3.4	6	15
4	575	7.2	8	12
5	612	3.8	7	14
6	624	3.9	7	16
7	645	1.8	8	16
8	655	2.4	8	15

The Donetz Coalfield.—An elaborate account of the Donetz coalfield in Russia is given by A. Brull.* The author deals at length with the geographical situation, the geology and the history of the district, the methods of working and the outlets for the coal, and the probable future production. This field lies on the right bank of the Donetz river, and covers over 9000 square miles. According to Grand'Eury, the strata belong to the middle zone of the second period of the Permian Carboniferous age. The nature of the coal varies considerably in the same seam, and the following varieties are found:—

	Fixed Carbon.	Ash.	Sulphur.
Anthracite	90-95	2.5	1.3
Non-bituminous	82-88	14-5	0.3-1.1
Semi-bituminous	74-82	2.6	0.3
Bituminous	69-71	15-4	5.1-6
Long flame bituminous	60-68	3-4	0.5-3

The anthracite is quite black, with a specific gravity of over 1.44. The seams are generally broken and less than 39 inches thick. The bituminous seams vary from 14 inches to 5 feet in thickness, and as a rule are regular and but little inclined, except near upthrows, which form local basins. Seams as thin as 28 inches are worked, but mining is generally difficult owing to the shale, which is greatly affected by water. The shafts are small as a general rule, and are often

* *Mémoires de la Société des Ingénieurs Civils*, vol. xlv. pp. 635-671.

square or rectangular, except in the larger collieries. Some inclined shafts are being worked. In the slightly inclined seams a pillar and stall system of working is adopted, the stalls being driven at right angles about 16 yards apart, leaving pillars 13 to 14 yards square, which are worked out backwards.

The coal is loaded by shoots into tubs holding about half a ton. The trams are laid with rails of 15 lbs. per yard on a gauge of $17\frac{1}{2}$ inches. Horse haulage is generally used. The largest winding-engine is one of 150 horse-power. The ropes usually employed are round iron or steel wire ropes, but flat manilla ropes are used for the largest engines. Single-decked cages are in general use, and safety appliances are rarely adopted. The mines are fairly free from water. Small quantities are dealt with by an automatically-acting water-tank under the cages or by pulsometers. Elsewhere pumps are employed, the largest pumping-engine being one of 240 horse-power. Most of the mines are naturally ventilated, but mechanical ventilators are coming into use. Safety-lamps are generally adopted.

The coal is often much mixed with shale, and in many instances is picked on rope belts. For coking, the coal is screened; but only one colliery has put up a washing-plant. Large quantities of coke are made in open ovens on the Schaumburg system. There are, however, some ovens of the Coppée type; but mixed coal has to be used, as some varieties adhere to the walls and render mechanical drawing impossible.

The number of the workpeople is about 20,000, and wages are higher than those usual in the neighbourhood. Most of the work is let out by contract to gangs of men. The average production per day is $2\frac{1}{2}$ tons per coal-getter in one colliery, or 13 cwt. per miner, if all the workpeople are taken into account. Details of the wages paid and the price of sinking and of other work are given.

The Laviana Collieries.—The coal found in these Spanish collieries occurs in the Lower Carboniferous horizon. In the northern portion of this district two groups of seams are met with, the one calcareous and the other siliceous. The latter is the more important, and the only one that has yet been worked. Five such seams occur, varying in thickness from 3 feet to over 4 feet, with a dip of from 30° to 35° . The coal contains but little ash, and cokes fairly well.*

The Turon Coal District, Spain.—The Turon valley lies between

* *Revista Minera*, vol. xliii. p. 148.

those of Aller and San Juan in the Mieres coalfield. At the San Victor mines six seams of coal are known, coursing N. 68° E., and dipping 48° S., their thickness varying from $1\frac{1}{2}$ foot to a little over 2 feet. At the San Pedro collieries the course is S. 16° E., with 50° dip to S.E., while at the Santo Tomas mines the seams course on the whole about N. 78° E., and dip from 58° to 80° S. The average workable thickness of coal is believed to be $1\frac{1}{2}$ foot throughout a large portion of this district, and it is estimated that 30,000,000 tons can be mined in the part referred to.*

The Coal-Measures of the Clarence Basin, New South Wales.—Mr. T. W. E. David† has issued a report on the seams of coal which have recently been opened out in the parish of Bungawalbyn, near Coraki. The geological occurrence of the coal is fully described with the aid of numerous sections, and numerous analyses of the coal are given. The percentage of ash (11.06 to 39.94) in the average samples is so high that it is evident that the coal could not be used for steam or other purposes in its present state. On the other hand, its richness in fixed carbon (45.87 to 74.13 per cent.), freedom from sulphur, and its character of being almost smokeless during combustion, should make it a useful coal for local purposes, if it could be cleaned by washing so as to reduce the percentage of ash. On an average, 1 foot 9 inches of the total coal in the "top seam" might be assumed to be the thickness of coal of quality sufficiently good for the local market.

Coal in British Columbia.—Among the many fields of work by the Geological Survey of Canada, described in the annual report, the observations of most economic importance relate to a very rich coal-field of the Kootanie formation in the south-east edge of British Columbia, about 200 miles from the Great Falls in Montana. Dr. A. R. C. Selwyn,‡ the director of the survey, estimates an area of not less than 144 square miles, containing some 50,000,000 tons of coal in each square mile, of which half on an average is available for mining. Twenty coal-seams were examined in the Crow's Nest Pass and westwards, showing a total thickness of 132 feet of coal. Three of these seams are respectively 30, 20, and 15 feet thick. On the eastern side

* *Revista Minera*, vol. xliii. p. 146.

† *Annual Report of the Department of Mines, New South Wales*, 1892, pp. 220-225.

‡ *Summary Report of the Geological Survey of Canada for the Year 1891*. Ottawa, 1892, pp. 1-60.

of the Elk River the series has twelve coal-seams, three of which are each more than 30 feet in thickness.

The Coal Deposits near the Canadian Pacific Railway.—

Large coalfields exist along the line of the Canadian Pacific Railway,* and natural gas is also found. The coalfield of Alberta extends from the station at Medicine Hat to that at Banff, and from the international boundary to the northern limit of the province, an area of about 40,000 square miles. The coal is in part good bituminous coal and in part lignite, the workable seams varying from 3 to 13 feet in thickness. The Medicine Hat lignites have been largely worked during the past five years. The output of coal obtained at the Lethbridge collieries is largely increasing. It is a semi-bituminous coal, the seams averaging 5 feet in thickness. A coal deposit at Crowfoot Creek is also being tested. The most easily workable coal, however, occurs at Barr River and Coal Creek. This coal yields a coke of good quality. Another extensive coalfield is that of the Canmore Basin, and anthracite mines are being rapidly developed in the neighbourhood of Banff, the anthracite being of excellent quality.

At Edmonton good coal is found at depths of from 10 to 100 feet below the surface, and is being actively worked. The coal deposits of British Columbia are so well known that they scarcely need mention; but, in addition to the deposits on Vancouver's Island, others have been met with on the mainland, notably in the New Westminster and Nicola districts.

The following assay † shows the quality of the anthracite produced at the mines existing in the neighbourhood of Banff, near the summit of the Rocky Mountains, on the line of the Canadian Pacific Railway:—

Fixed Carbon.	Volatile Matter.	Ash.	Water.	Total.
87.18	9.15	2.63	1.04	100.00

This coal is largely used on the Canadian Pacific Railway, and also by steamships in the Pacific.

The Collieries of Vancouver Island.—In a recent report to the United States Senate, Mr. Myers ‡ states that there are four large collieries in operation in the island. Three of these are situate in the

* *Mining Journal*, vol. lxii. p. 877.

† *The Coal Trade Journal*; *American Manufacturer*, vol. li. p. 241.

‡ *American Manufacturer*, vol. li. p. 593; *Engineering and Mining Journal*, vol. li. pp. 394-395.

Nanaimo coalfield, the area of which is estimated at 200 square miles. Another colliery has been opened up in the Comox coalfield, the area of which is some 300 square miles. The coal is found in seams varying from $2\frac{1}{2}$ to 11 feet in thickness. The mines are mostly worked by vertical shafts, varying from 200 to 690 feet in depth. The coal is a semi-bituminous variety, that of the Nanaimo field assaying—

Fixed Carbon.	Volatile Matter.	Water.	Ash.
54.7	33.7	4.6	7.0

Tests of South African Coal.—Mr. T. Quentrail* gives the following results of some careful tests of the relative value of British and South African coal:—

Kind of Coal.	Lbs. of Water Evaporated per Lb. of Coal from 212° F.	Percentage Value, taking British Coal at 100.
Vaal Drift, Transvaal	5.28	49.12
Newcastle, Natal	9.24	85.96
Indwe, Cape Colony	7.09	65.25
Lewis and Marks, Transvaal	6.73	62.64
Newcastle, Natal (2)	8.52	79.26
Kroonstad, Free State	7.08	65.89
Welsh colliery, Natal	8.26	76.87

The British coal taken as standard was Nixon's Steam Navigation coal, which gave 10.75 lbs. of water evaporated. The tests were made from time to time at the Beely boilers at the De Beers diamond mine.

The Natal Coalfields.—Mr. J. P. Hamilton† is satisfied that Natal contains a very good quality of steam coal which can be cheaply worked, and can compete with British coal. The coal-measures form a large area to the north of the colony; the nearest workable seams to the coast are at Elands Laagte colliery, 204 miles from Durban. Here three seams have been found at depths from the surface of 63, 100, and 151 feet. The coal sometimes varies considerably in very short distances, and has been proved to be actually worthless in some collieries. The quantity of coal available in Natal is estimated to consist of equal proportions—518,400,000 tons—of anthracite, semi-bitu-

* *Reports of the Inspectors of Diamond Mines in the late Province of Griqualand West* Cape Town, 1892, p. 13.

† *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 81-890.

minous coal, bituminous coal, and free-burning bituminous coal, or in total, 2,073,600,000 tons. An assay of an average sample of the anthracite found at Gladstone gave—

Fixed Carbon.	Volatile Constituents.	Water.	Ash.
81.05	4.38	2.34	12.23

Summing up generally, the author concludes that the colony of Natal possesses a superior class of coal for commercial purposes, better than any Indian coals he knows. From repeated trials under boilers he is of opinion that Natal coal is 15 per cent. inferior to best Welsh coal; but against this the price paid at the various ports has to be taken into account, and in several instances Natal coal can come to the fore.

Coal in the Transvaal.—According to Mr. W. Gibson,* patches of coal-bearing beds exist in many places around Boksburg and Heidelberg, and in some cases are worked for coal. The coal-seams are without underclays, while sandstones form interstratified layers. Compared with English types the coals are of inferior quality, containing a large percentage of incombustible matter. On the Nigel Mynpacht mine property, coal is worked, the beds being identical with those of the Orange Free State. In the Heidelberg and Boksburg district the coal lies in detached basins. These basins are very shallow in the Transvaal, but in the Orange Free State the coal strata will probably be found to constitute much thicker deposits, while it is certain that they cover much larger areas than in the neighbouring republic. The coals are probably of drift and lacustrine origin. In the Orange Free State the coal-beds are of acknowledged Upper Karoo and Lower Stormberg age, and it seems certain that the coals of the Transvaal and of the Orange Free State belong to one and the same geological formation.

Coal on the Great Tenasserim River, Lower Burma.—The existence of coal at various places on the Great Tenasserim River has been known since 1838, and a coal-seam was worked experimentally in 1843. The discovery of coal announced this year is therefore a re-opening, and is only so far new in that coal has been proved at another point. Mr. T. W. H. Hughes† reports that the coal crops

* *Quarterly Journal of the Geological Society*, vol. xlviii. pp. 404-437.

† *Records of the Geological Survey of India*, vol. xxv. pp. 161-163.

out in the Hti-phan-ko stream, a tributary on the right bank of the Great Tenasserim River. Two exploratory pits sunk show that the seam is 12 feet 7 inches thick, of which 7 feet 7 inches consists of coal. The dip is as much as 32°. Assays of these samples from different parts of the bed gave the following results:—

Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Total.
15.20	30.08	30.86	23.86	100.00
10.80	27.36	42.52	19.32	100.00
11.34	36.40	43.27	8.99	100.00

The commercial value of the Tenasserim field depends upon questions other than those of the quality or the quantity of the coal, but it is a strong point in its favour that the coal is above the average Indian standard. The quantity of coal, too, is abundant. The locality is, however, unfortunately situated for labour, transport, and shipment. A market other than the local one would have to be found. Two exist, in Rangoon and Penang, in both of which there would be a large sale for a good steam coal at low rates.

Coal in the Country North of Bhamo, Burma.—In a geological sketch of the country north of Bhamo, forming the frontier between Burma and China, Mr. C. L. Griesbach * notes that the hill ranges which bound the Irrawaddi river valley are practically barren of all useful minerals. The only traces of coal which occur within the area described are found ten miles west of Mogaung, but they appear to be of little value. Occasionally small quantities of lignite are brought to Myitkyina for sale. This mineral comes from Talang, where there is a seam 2 to 3 feet in thickness. The Kachins sell this lignite at 8 annas a basket, and it need scarcely be said that it would be cheaper to import British coal at this rate.

In a report on the amber and jade mines of Upper Burma, Dr. F. Noetling† incidentally alludes to the Mogaung coalfield. It might more properly be called the Saungka coalfield, the outcrops of the seams being situated along the bank of a small stream of that name. There is no doubt that the coal is of Tertiary age. The hills to the east consist of metamorphic rocks, whilst those to the west consist of crystalline limestone. Whatever may be the thickness of the coal-seams their area is very limited, and it is highly probable that the strata are much disturbed.

* *Records of the Geological Survey of India*, vol. xxv. pp. 127-130.

† *Ibid.*, pp. 130-135.

Coal in Tonkin and Annam.—Of the collieries which are at present in operation in Tonkin and Annam, the most important are those at Hongkay, forty-five miles from Haiphong. These collieries have been worked for two years by a French company with a capital of £160,000. Although trials of this coal on French gunboats have proved successful, it is not absolutely certain that there is a large supply of thoroughly good coal.

Collieries are also being worked at Kebao, an island off the coast of Tonkin, and the coal has proved satisfactory for ships' use, the engine making sixty-five revolutions per minute compared with sixty-nine when Cardiff coal was used.

Lastly, the collieries of Tourane in Annam, formerly worked by the Chinese, are now in the possession of a French company, and yield a fairly good steam coal.*

The Coalfields of Malaysia.—A long and detailed account of the coalfields of Malaysia is given by Messrs. J. A. Hooze, R. A. Eekhout, and R. A. van Sandick.† In these Dutch East Indian possessions only the lower unproductive strata of the Carboniferous formation are found. All the coal is of the Tertiary formation, that belonging to the Lower Tertiary being the best, whilst the Upper Tertiary produces only brown coals and lignites. The island of Sumatra is the best known at present, and a railway is there being opened to connect the Oembilin coalfield with the coast to convey an annual output of 100,000 tons. There are from three to seven seams in this field, with a total thickness of about 30 feet. The total quantity of coal in the whole field is about 200,000,000 tons, of which a large proportion can be worked from adits, and the rest by shallow shafts. Details of the various sections of the field are given. The coal is hard and black, containing very little ash, and is well adapted for steam-raising purposes. Coal deposits have also been found in many other parts of the island. Java also contains several localities in which coal has been found, but in most cases the seams are not good, and the coal is generally impure. Small amounts of petroleum have been found in Madura, and brown and other coals have also been discovered in some of the smaller islands. Borneo, however, contains the most important coal deposits of all the islands of the Archipelago. The best of these deposits exist in South and East Borneo, and one of the largest basins

* *Berg- und Hüttenmännische Zeitung*, vol. li. pp. 259-260.

† *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 323-358.

lies round the river Barito, and covers over two degrees both of latitude and longitude. The southern part of this field is best known. It contains from six to eleven seams, of which from two to six are workable. The dip is generally low, but the percentage of ash is high, due to the slate partings. Much resin occurs in all the Borneo coals, as much as 2 per cent. being found in some instances. The first mine was worked by the Dutch Government in 1846 at Riam, and since then a good deal of coal has been extracted in the vicinity, but the mines are now all closed. There have also been at various times many other workings, and numerous details of the different districts are given. The following are assays of some of the coals produced in these districts:—

Formation.	Region.	Moisture.	Ash.	Sulphur.	Coke.
Lower Miocene	1. Sanga Sanga	14.00	1.22	0.72	34.60
Lower Miocene	2. Pelurang	14.40	1.60	0.50	55.40
Lower Miocene	3. Salili-Prangat	12.14	3.80	2.35	55.10
Lower Miocene	4. Batoo Pangal	10.40	4.00	1.70-2.25	52.90
Upper Miocene	5. Lerong-Tenggaloeng-Ajam	20.65	3.65	0.33	51.30

The Lower Miocene coals are estimated to have a value of 75 per cent. of English coal. Out of districts Nos. 2, 3, and 4 it will be possible to extract a million tons of coal by adits within $1\frac{1}{2}$ mile of the river Kotei. In the provinces of Berouw some rich coal-basins are also found, in the richest of which there are some eleven workable seams, with $61\frac{1}{2}$ feet of workable coal, of a quality closely resembling those given above. The extensive fields which exist in North Borneo and in British Borneo are not considered by the authors.

Coal in Sumatra.—F. Kleye* has discovered, in the province of Bilah, on the east coast of Sumatra, on the rivers Batoo, Porkas, and Saliuching, extensive beds of brown coal of excellent quality. Hitherto the occurrence of brown coal had been observed only on the west coast, where mining has been carried on at a profit for some time past. The coal occurs in beds of from 3 to 8 feet in thickness, and at a slight depth below the surface. It is usually overlain by an argillaceous sandstone.

Coal in North Carolina.—A deposit of semi-bituminous coal.

* *Berg- und Hüttenmännische Zeitung*, vol. li. p. 208.

which yields a coke of good quality, is about to be exploited in Stokes County, North Carolina. One seam is 36 inches in thickness, and another is 54 inches. A third seam also exists. It is estimated that the cost of mining, including loading on railway waggons, will be between 2s. 8d. and 3s. a ton.*

Coal in Colorado.—At the head of Horse Gulch, Hesperus, Colorado, is a deposit of coal which is now being worked. The seam attacked is between $5\frac{1}{2}$ and 6 feet in thickness, and the coal is stated to be of excellent quality. A branch railway is being constructed to this property to connect it with the Rio Grande Southern Railway. The output will shortly be between 300 and 500 tons a day.†

A shaft is being sunk by the Long's Peak Coal Company with a view to open up a large seam of coal. In doing this another seam 3 feet in thickness has been encountered.‡

The Coalfields of Montana.—An account is given by Mr. W. H. Weed§ of the coalfields of Montana, which at present are only worked to a small extent. There is good reason to believe that an almost continuous stretch of coal-bearing strata will be found along the foot-slopes of the Rocky Mountain chain. At the eastern end is the Rocky Fork coalfield, west of which is the Bozeman field, and smaller fields continue till the Judith Basin and the Great Falls field are reached. From the Missouri northwards coal-bearing rocks have been found, and working begun at the Birch Creek Basin. All the Montana coals are of Cretaceous age, and are found over the mountain limestone of the Carboniferous period. In ten counties there were twenty-three mines worked with an output of 362,180 tons in 1889, and this increased to 517,477 tons in 1890. A map of Montana is given showing the outcrops of bituminous coals and the position of lignite mines. In the Rocky Fork field, near Bear Tooth Mountains, there are eighteen seams exposed, of which eleven are over 6 feet in thickness, with a dip of 18° to the south. Six seams have been worked. The coals vary from household to steam coals, and an assay of No. 4 seam shows—

Moisture.	Volatile Matter.	Fixed Carbon.	Ash.
8.11	43.29	46.56	2.04

* *American Manufacturer*, vol. i. p. 373.

† *Ibid.*

‡ *The Salt Lake City Daily Tribune*, July 26, 1892.

§ *Engineering and Mining Journal*, vol. liii. pp. 520-522, 542-543.

The coal is here of Laramie or Fort Union age. West of this is the Bozeman field, which has not been fully explored. There are, however, several workings, and there are several known seams, three of which are over 5 feet in thickness. In this field at Cokedale, for instance, the coal is of fair steam quality, and can easily be mined. It will not coke. The Cinnabar field is an isolated area of small extent, but it yields the best coal at present mined. Sections are given of the coals found here. The Horr coal makes good coke, and there are sixty ovens in operation. The Gallatin and the Judith fields require to be opened up by a railway. In the Great Falls coalfield only one workable seam has been found, but a large production is predicted. This seam varies from $3\frac{1}{2}$ to 7 feet in thickness; the upper part is somewhat anthracitic, the middle a bright bituminous coal, and the lower part is a coking coal. The seam has a dip of 3° , and is easily mined. An average assay shows—

Volatile Matter.	Fixed Carbon.	Water.	Ash.
33.15	57.05	3.98	5.83

Further information is given with regard to the coal in this State by Mr. H. Wood,* who describes the Flathead coal basin. In this field from fifteen to twenty seams have been observed, and of these at least six or seven are workable.

According to Mr. W. H. Weed,† the Great Falls coalfield, belonging to the Kootanie formation of Lower Cretaceous age, extends from the sources of the Judith River north-westerly at least 125 miles. Its thickest coal-seam known, $3\frac{1}{2}$ to 7 feet thick, is mined at Sand Coulee. A smaller coalfield is mined at Red Lodge, where nineteen coal seams have been examined, six of them varying in thickness from 5 to 13 feet. The strata dip about 15° southwards, terminating at the fault that runs along the northern base of the Beartooth range, which includes the highest peaks in Montana.

The Bituminous Coalfield of Pennsylvania.—Mr. I. C. White ‡ has prepared an exhaustive report on the stratigraphy of the bituminous coalfield of Pennsylvania, Ohio, and West Virginia. The classification he adopts partly preserves the subdivisions and nomenclature of Messrs. W. B. and H. D. Rogers, such new features being

* *Engineering and Mining Journal*, vol. liv. p. 57.

† *Bulletin of the Geological Society of America*, vol. iii. pp. 301-330.

‡ *United States Geological Survey. Bulletin No. 65*, pp. 1-212.

added as now seem necessary from the present wider and more detailed knowledge of the coal-bearing strata. The entire Carboniferous system of the Appalachian region comprises three great divisions, founded on the conditions of their deposition. The lower division is exclusively marine. The middle division consists of shore deposits, and includes the lower coal-measures. Lastly, the upper division embraces only fresh and brackish water deposits, and includes the upper coal-measures, and the Permo-Carboniferous series of Dunkard Creek. The greater portion of the volume is occupied by a description of the outcrops and stratigraphy of the five series into which the Upper and Middle Carboniferous systems are divided.

The geology of the Lower Coal-measures of Monongalia and Preston counties, West Virginia, is fully described by Mr. S. B. Brown.* The coal districts of Pennsylvania are also exhaustively dealt with by Mr. H. M. Cadell.†

Lignite in Texas.—In the Report of the Geological Survey of Texas for 1891, Dr. T. B. Comstock describes the lignite field as far as surveyed by him in that year. As a rule the lignite is of good quality, and is well situated for economic mining in many localities. It has been worked in a few places near the surface, the Hartz mine being the most extensive. Here the principal seam is a member of the Upper Cretaceous series. Mr. W. Kennedy gives some information about the lignites in Eastern Texas, where the deposits cover a large area and the seams are also near the surface. The upper bed has a thickness of 8 feet, varying to 13 feet on the dip. At the Alba mine the seam is 8 feet thick, and is worked on a pillar and stall system.

The Calvert Bluff lignite, or brown coal, deposits near Calvert, Texas, have been purchased by a company, who will at once begin the briquetting of the fuel. This is one of the direct and practical results from the investigation by Mr. Dumble, the State geologist, of European methods of utilising brown coal, and from his attempts to initiate such utilisation of brown coals in America. The term *lignite*, as generally used in America, is erroneously applied, most of the varieties of coal so called being either brown coals, pitch coals, or glance coals. The term *lignite* is properly applicable to the charcoal-like varieties which retain more or less perfectly the woody structure.‡

* *The American Geologist*, vol. ix. pp. 224-228, with plate.

† *Transactions of the Mining Institute of Scotland*, vol. xiii. pp. 242-262, with six plates.

‡ *The American Geologist*, vol. x. p. 262.

The Pocahontas Coal Region.—Mr. J. D. Weeks,* in an official report, describes the Flat Top coke region of the Pocahontas coalfield. This district is the main source of supply of the coke required for the furnaces of Virginia, and, to some extent, of Northern Alabama. This census report refers to the year 1889. There were then 2464 coke ovens either erected or in course of erection, and the value of the coke at the ovens made during the year amounted to £108,500. Other details show that up to the end of the year 1890 there had been mined in this district 8,237,734 tons of coal, 899·7 acres of coal lands having been exhausted, whilst some 175,000 acres still remain. The average yield of coal has thus far been 9156 tons per acre.

Coal in the Argentine Republic.—In an account of the mines in the Argentine Republic, Mr. H. D. Hoskold † deals with the several occurrences of coal and lignite. Samples of lignite from Paganzo, where it occurs in considerable quantities, show on assay—

Water.	Fixed Carbon.	Ash.	Volatile Matter.	Total.
8·85	65·30	1·70	24·15	100·00
7·38	65·34	4·74	22·54	100·00

Four borings have been made, and sections of the strata passed through are given. Coal has been recently discovered near San Rafael, in the south of the province of Mendoza, and an assay shows—

Water.	Volatile Matter.	Fixed Carbon.	Ash.	Total.
2·05	49·51	47·81	0·63	100·00

Six seams are reported to exist, the principal being over 3 feet in thickness. The ash of the above coal, according to an assay by Dr. Kyle, contains 38·22 per cent. of vanadium pentoxide. In Neuquén, coal has also been discovered, and samples assay as follows:—

Water.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Total.
9·05	33·60	53·90	3·55	trace	100·00
3·75	35·42	50·18	10·65	trace	100·00

Lignite in Chili.—The fuels now used in Chili, according to C. Vattier, ‡ in a communication on the mining, metallurgical, and other industries of that country, are the native woods and lignites, and imported coal, coke, and anthracite. The principal lignite mines lie

* *Census Bulletin*, No. 200.

† *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 418-446.

‡ *Mémoires de la Société des Ingénieurs Civils*, vol. xlv. pp. 37-140.

in the province of Bio-Bio, near Concepcion, at Lota Coronel, Aranco, and Lebu. Carboniferous deposits are also met with near Valdivia, and to the south of the island of Chiloe, in the island of Huafo, and near the Magellan Straits, but have not been worked at the last-named place. The lignites are mostly sea-borne, and sell at about 27s. per ton, the output being about 600,000 tons per annum, much of which is used by steamers. At Lebu the lignite is washed. The following are two assays :—

Situation,	Water,	Volatile Matter.	Fixed Carbon.	Ash.	Total.
Buen-Retiro	4·8	40·8	48·2	6·2	100·00
Lota	5·0	40·2	53·2	1·6	100·00

They contain from 0·02 to 0·1 per cent. of sulphur, but the southern lignites hold more. The seams vary from 2 to 4½ feet in thickness. Coke made from the lignites is not of quality suitable for iron manufacture.

Coal in Ecuador.—In a Foreign Office Report, Mr. W. H. D. Haggard * refers to the discovery of a coalfield near Riobamba, and states that he is informed that the coal is a good bituminous variety. Riobamba is about midway between Guayaquil and Quito. Should the coalfield prove of the value anticipated, the port of Guayaquil will provide a ready means of export.

Coal in Mexico.—In a description † of the mining industry of the Mexican territories of Coahuila and Nuevo Leon, it is pointed out that the production of coal in San Felice from March 1, 1888, to January 1, 1889, amounted to 55,000 tons. The production of the Hondo mine amounted to 31,118 tons. An assay of the coal gave the following results :—

	Per Cent.
Water	0·74
Volatile constituents	17·84
Fixed carbon	65·92
Ash	15·50
Total	100·00
Sulphur	1·41
Coke	81·42
Specific gravity	1·34

* *Reports from Her Majesty's Representatives Abroad.* Miscellaneous Series, 1892, No. 262.

† *Berg- und Hüttenmännische Zeitung*, vol. li. p. 216.

The coke obtained from the coal yielded—

	Per Cent.
Water	0.55
Volatile constituents	2.09
Fixed carbon	81.82
Sulphur	0.78
Ash	14.76

The colour of the ash is red.

Up to the present no foreign mining company has commenced coal-mining in Mexico. In 1890 coal was discovered at Jalesco, on the shores of Lake Chapala, as well as in the Ameca and San Gabriel valleys. Deposits of coal have also been found in the States of Tlaxcala, Veracruz, Hidalgo, Tamaulipas, and Nuevo Leon. Some of the coal of this latter State is used on the line of the Mexican National Railway. Lignite and peat are found in many parts, but are little used. One of the seams in the San Marcial coalfield, Sonora, is 5 feet thick, and only 17 feet below the surface.*

Coal in Peru.—In a description of the coal and mineral resources of Peru, Mr. E. Lane † says that the vast coal deposits have scarcely been touched. Good bituminous coal is found in the department of Junín, not far from Oroya, to which town a railway will shortly be opened. Coke has been made from this coal. At Cerro de Pasco, near the railway, bituminous coal is also found. Anthracite coal is found in the department of Ancachs, contiguous to a proposed railway, and large deposits also occur on the Santa River, near Caraz. It is also abundant in the province of Huamachuco, and two mines are worked near the town of the same name in beds of $4\frac{1}{2}$ and $6\frac{1}{2}$ feet thick. At Llaray the coal is 13 feet in thickness. Large deposits of lignite occur in the departments of Arequipa and Puno. Timber is abundant, but its transport is difficult.

The Coalfields of New Caledonia.—L. Pelatan ‡ observes that it was known even before the French annexation in 1853 that the islands of this group contained deposits of coal, several having been noted by Montrousier in 1846. They were not worked at all, however, until 1864, when M. Garnier made some preliminary experimental

* *Revista Minera*, vol. xliii. p. 109.

† *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 763-772, with map.

‡ *Génie Civil*, vol. xxi. pp. 327-328, 347-350, and 360-363.

work. He came to the conclusion that there was no workable coal in the colony. Now, on the other hand, this is known not to be the case. There are two main coal basins, those of Noumea and of Moindou. The Noumea basin extends for a length of about thirty-one miles, following the course of the immense eruption of magnesian rocks. In breadth it varies between about half a mile and a mile and a quarter in the southern part of the Noumea peninsula, while in the northern portion its width reaches as much as five miles and a half. The area is estimated at about 62,000 acres. A number of coal-seams have been discovered, and the author refers to the work that has been done in connection with them. He considers various sections of the coalfield, showing by illustrations the probable erosion of the coal-seams, and the course of the portions of the seams still remaining. The Moindou coalfield is similarly considered. It is larger than that of Noumea, its greatest length being about forty-four miles, and its area 100,000 acres. It is much less known than is the Noumea field, being at a considerably greater distance from the capital. Some seams of considerable thickness have been found. The following are some assay results of the New Caledonia coals:—

Coalfield.	Fixed Carbon.	Volatile Matter.	Ash.	Calorific Power.
	Per cent.	Per cent.	Per cent.	Calories.
Noumea	62.20	32.00	5.30	6159
Noumea	73.00	17.00	10.00	...
Noumea	82.75	6.25	11.00	7199
Moindou	61.73	37.05	1.22	...
Moindou	74.23	26.00	1.77	6842
Moindou	86.50	6.50	7.00	7037
Vok	78.25	9.00	12.75	6885

Peat.—Professor W. Smith and Mr. W. M. Travers * describe the peat exposed in the Blackwall tunnel. It contains 69.5 per cent. of moisture and 30.5 per cent. of dry carbonaceous matter, of which 50.08 per cent. is ash. Benzene extracted 0.16 per cent. of wax or bitumen.

* *Journal of the Society of Chemical Industry*, vol. xi. p. 591.

III.—CHARCOAL.

Fuel Supply of the Salem District, India.—In a report on the iron industry of Salem, Mr. T. H. Holland * states that the fuel used is entirely charcoal. For the preparation of charcoal, the favourite wood seems to be the *Wunjai* (*Albizzia amara*)—the *Oosulay* of Malabar. The timber is extremely hard, and mottled with concentric alternating light and dark bands. Other less favourite woods used by the pariahs of the Salem district are—

Sembalichan (*Erythroxylon indica*), a dark brown wood.

Nekani (*Canthium didymum*), a hard grey wood.

Woodavai (*Grewia rothia*).

In the vicinity of the iron-bearing beds there is sufficient timber to supply charcoal for the following yield of iron per annum :—

	Timber.	Iron
	Tons.	Tons.
Salem	5,736	400
Attur	833	58
Namakal	5,366	416
Uttamkam	8,140	625
Totals	20,075	1,499

It has been suggested that fast-growing trees, such as *Casuarina* and *Eucalyptus*, might be employed for producing timber suitable for charcoal manufacture. This suggestion is not supported by the author. He thinks, however, that they would replace, as fuel for railway and towns, the hard timbers which are found to be suitable for charcoal, and that thus the cost of the carbonised product would indirectly be reduced. As to the nature of the wood necessary to produce a good charcoal but little is known. Experience shows that the natives prefer hard close-grained woods, these properties being desirable probably on account of the firmness of the charcoal and the small percentage of ash.

Charcoal in Chili.—Up to the present time charcoal has not, according to C. Vattier,† been much used in Chili as a fuel, partly on account of its cost. In the southern part of the country it could, however, be

* *Records of the Geological Survey of India*, vol. xxv. pp. 135-159.

† *Mémoires de la Société des Ingénieurs Civils*, vol. xlv. pp. 37-140.

delivered at the furnaces at 22s. per ton, and experiments have proved that it is equal in quality to the European product. In the south, wood can be procured in great abundance in several varieties, each of which is well adapted for use as a fuel.

The Destructive Distillation of Wood.—Some researches have been made by Mr. J. C. Chorley and Professor W. Ramsay* on the destructive distillation of wood. Oak, beech, and alder were the woods treated. They were heated in a glass vessel partly exhausted of its air, and the products of distillation were collected and examined. The effect on the production of charcoal of the rate of distillation is clearly shown in the tabulated results. With rapid distillation the yield of charcoal is considerably lessened, whilst that of carbonic anhydride and of the other gases is largely increased. The total weight of the distillate is not greatly affected. For the different kinds of wood, the productions of charcoal, both at high and low temperatures, do not differ appreciably. The change of wood into the products of distillation is an exothermic change, wood having somewhat the nature of an explosive. That is, the temperature of the wood rises above the external temperature as it decomposes, and curves are given to show this effect. This has been noticed during distillation on a large scale.

IV.—COKE.

Coke from New South Wales.—Mr. J. C. H. Mingaye† gives the following results of the analysis of a sample of coke made from coal obtained from Mount Pleasant colliery, near Wollongong:—

Water	Volatile Matter.	Fixed Carbon.	Ash.
0.20	0.50	85.85	13.45

The specific gravity was 1.565; the percentage of sulphur in the ash was 0.25; the ash was white in colour and contained—

SiO ₂ .	Al ₂ O ₃ .	Fe ₂ O ₃ .	CaO.	MgO.	K ₂ O.	SO ₂ .	Total.
51.10	40.20	2.80	3.19	0.64	1.76	0.85	100.54

The coke is blackish grey in colour, well made in fairly long lengths. From its hardness it should be readily handled without much breakage, and is equal to standing the weight of a heavy burden of ore and flux.

* *Journal of the Society of Chemical Industry*, vol. xi. pp. 395–403.

† *Annual Report of the Department of Mines, New South Wales*, 1892, p. 278.

Coke in Virginia.—The Pocahontas Flat Top coal region in Virginia has rapidly sprung into prominence, according to Mr. J. D. Weeks,* on account of the excellence of the quality of the coal for fuel and coking purposes. The seams belong to the lowest member of the coal series. There are at least three workable seams above water-level, but only one is as yet being worked. This seam varies in thickness from 11 to 13 down to 5 feet, but it averages 9 feet at Pocahontas, and it contains no partings except a streak of bone coal. The measures are almost horizontal, and are free from faults and other disturbances. The coal is semibituminous, somewhat dull in lustre, and has to be blasted. An assay of the coal gives—

Volatile Matter.	Water.	Fixed Carbon.	Sulphur.	Ash.
18·81	1·01	72·71	0·787	5·19

The run of the mine cokes fairly well, but the coke is much improved by crushing the coal. The yield of coke is stated to not exceed 62·5 per cent. in many instances. All the ovens in use are of the beehive type, those recently constructed being 12 feet in diameter and 7 feet high, though some makers prefer them rather smaller. Some successful experiments have been made with the Soldenhoff-Coppée oven, giving a yield of 67·5 per cent. in 36 to 48 hours. The charge for the beehive oven varies from 9000 lbs. for 72 hours to 8000 lbs. for 48 hours. The cost is given by various authorities as from 5s. 7d. to 7s. 3d. per ton; a detailed average given by the author totals up to 6s. 8d. Three assays of the coke are as follows :—

Water.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
0·70	1·27	91·43	6·09	0·509
0·66	1·06	92·82	4·91	0·548
0·35	0·76	92·55	5·75	0·597

Various statistics and other details of cost are given, and the whole subject of the coal, the coke, and its uses are treated in a most comprehensive manner.

Manufacture of Coke.—According to Rossigneux,† in 1889 Europe produced 22,195,000 tons of coke, of which Great Britain produced 63 per cent., Prussia 20 per cent., Belgium 10 per cent., France 5 per cent., and Moravia 200,000 tons, whilst the United States produced in the same year 8,500,000 tons. The theory of

* *Census Bulletin*, No. 200, Washington, Aug. 2, 1892.

† *Bulletin de la Société de l'Industrie Minière*, vol. v. pp. 387-477, 505-589.

coking is fully discussed by the author in his lengthy paper, and he describes the various coking processes in heaps, stalls, beehive ovens, and the principal coke-ovens introduced of late years.

Some notes on several types of coke-ovens are given by Mr. T. W. H. Mitchell,* showing their advantages and disadvantages. In the Coppée oven the heat is so intense that it makes good coke from inferior smudge, and the average yield is 10 to 12 tons per oven for three to four years, but after that time the yield falls off unless extensive repairs are made. The labour cost is low owing to the system of pushing out the coke, and the space occupied is small. The coke has not, however, such a good appearance as beehive coke, and also the prime cost and the maintenance are high. The intricate connections between the ovens necessitate several being laid off when one is being repaired. As the coke is watered outside the oven, it is dull. The furnace or oblong oven produces coke which fetches a better price than the Coppée coke. The ovens can be drawn by an anchor, but the side flues are constantly giving way or getting blocked up. The yield does not exceed 6 tons per week from Silkstone smudge. The Dixon and Breckon oven occupies twice the area of a Coppée oven. It cokes 12 tons per week and yields 10 per cent. more coke from the coal than a beehive oven. As coking proceeds both from top and bottom, there is a parting in the middle. The beehive oven is simple and durable, and the cost of repairs is low. Mechanical means for drawing the coke have been adopted with success in several instances. The D-shaped oven gives a greater yield of coke than a beehive, which occupies the same area, while the construction is even more simple, though it is not quite so strong. The necessity for crushing and washing the coal is also discussed.

The Semet-Solvay Coke-Oven.—F. W. Lürmann† states that ovens on this system have been in use in Belgium for the past five years, 205 being now erected while 140 are in course of construction. The oven is well suited for the coking of badly caking coals, and works with considerable rapidity, a charge of from 4 to 5 tons being finished in less than twenty-four hours. The sides are made extremely thin, with horizontal side flues; but solid fire-brick pillars from 15 to 20 inches in thickness are left between the ovens, and these serve as an important storage reservoir for heat, greatly diminishing the "dead point" of the

* *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 498-506.

† *Stahl und Eisen*, vol. xii. pp. 828-832, with three illustrations.

charge. These pillars serve, too, to protect the thin walls of the oven itself by taking off the weight of the roof and its covering, the two together having a thickness of from 39 to 47 inches. This thick covering acts as another most important heat reservoir. So important, indeed, is this heat storage that it quite takes the place of and renders unnecessary any special arrangements for the heating of the air required for the combustion of the gas. The oven is thus of simpler form and consequently less costly to erect. Thus, while an Otto-Hoffmann oven with its regenerative chamber costs £250, one on the Semet-Solvay system costs about £210, or 16 per cent. less. The author proceeds, moreover, to show that even if the two ovens cost alike, the Semet-Solvay one would be relatively over 31 per cent. the cheaper of the two, owing to its larger annual output. Further, these latter ovens show an extremely high boiler evaporative power for the waste gases, a battery of twenty-four such ovens at the Phoenix Works evaporating 138 tons of water in the twenty-four hours, this again, as the author shows, being a very great saving when comparing these ovens with those of the Otto-Hoffmann type. The author also places the cost of a condenser plant for the volatile products of the coking at £300 in the case of a Semet-Solvay oven, as compared with £350 for the Otto-Hoffmann ovens. Estimates are given showing the cost of erection and returns obtainable from ovens built on this Semet system.

The author's statement that in the Semet-Solvay coke-oven a charge of from 4 to 5 tons of semi-bituminous coal could be coked in twenty-four hours, and that with a battery of twenty-four such ovens, the gases passing from them would suffice to heat 3265 square feet of boiler surface, is doubted by the Otto Company.* They consider that for one of their ordinary ovens, without condensation of the by-products, not more than 108 square feet of boiler-heating surface can be allowed, even when bituminous coal is being coked. They also compare their own ovens favourably with those of the Semet-Solvay type.†

New Forms of Coke-Oven.—Mr. H. Kennedy ‡ has designed and erected at Coketon, Pennsylvania, a self-discharging form of coke-oven. The oven proper consists of a cylindrical frame of plate steel 6 feet high by 12 feet 6 inches in diameter, strengthened and stiffened by a 6 by 6 inch angle iron, and made sufficiently strong to resist all expansion of the brick-work during the coking process. To the cylindrical

* *Stahl und Eisen*, vol. xii. p. 878.

† *Ibid.*, p. 879.

‡ *Iron Age*, vol. I. p. 529.

shell are securely riveted heavy wrought-steel brackets inclosing four steel axles bearing directly on waggon wheels. These brackets and wheels are braced and stiffened to avoid sagging. This oven frame is then placed on wheels and lined like an ordinary beehive oven. It has no contact with the foundation except through the wheels to the rails, the arch resting on 6 by 6 inch angle iron. The coke is not cooled inside the oven, but the oven is pushed bodily forwards, and the hot coke is ejected into a pit in front of the oven, where it can be cooled in the ordinary way, the oven itself being returned to its former position uncooled.

In the Festner-Hoffmann coke-oven the regenerative chamber, as used in the Otto-Hoffman oven, is replaced by a "recuperator" system—a number of channels, the sides of which are heated by the waste products of combustion. These give up their heat in this manner to the incoming air, which finally attains a temperature of about 900° C. The cost of such an oven is about £200.*

An illustration is given † of a coke oven with enclosed hearth inclined so that the coke will slide out. There is a hydraulic feed, and also means for drawing off the gases. Air enters the fuel through narrow openings in dwarf walls covered with iron sheets, by means of which the coke is prevented from attachment. The coke is drawn into a gridded shoot, in which a supply of water can be distributed, so that by the removal of a door the coke is allowed to fall into trucks.

Coking under Pressure.—In a paper read before the Berlin Society of Arts an account is given by Quaglio ‡ of the various methods that have been adopted for the coking under pressure of badly coking coals. After referring to the methods in use for the collection of the by-products, the author passes to the various experiments which were made to obtain good coke from coals which caked to a slight extent, by breaking the coal down into small pieces and then compressing it before submitting it to the coking process proper. In the Schaumburg oven this was done by stamping the coal down in the furnace itself; in the Lürmann oven, by ramming in fresh coal by means of a plunger and hopper placed at the end of a retort. The use of heavy stones placed as weights on the top of the coal during the coking is also mentioned. The stamping method was developed by Ritter von

* *Stahl und Eisen*, vol. xii. p. 827, with sheet of illustrations.

† *Industries*, vol. xiii. p. 32.

‡ *Verhandlungen des Vereins zur Beförderung des Gewerbfleisses*, 1892, pp. 146-154.

Mertens at Trzynietz, in Austrian Silesia, who stamped the finely divided coal into sheet-iron receptacles, and then charged these into the coke-oven. Baumgarten improved on this, and the modified method he introduced is still in use. He employs a sheet-iron receptacle of the same dimensions as the interior of the coke-oven, with movable sides and bottom. The coal is stamped into this, the sides are swung back, and the bottom, with the compressed coal resting on it, is charged into the oven, the metal bottom being then withdrawn. Other modifications of this method are also described, and statistics are given relating to the number of such ovens in use at various works.

The Utilisation of the By-Products from Coke-Ovens.—B. Leistikow,* in a paper read at the meeting of German Mining Associations at Breslau, sketches historically the methods that have been proposed or adopted for the collection of the by-products from the coking process, and then describes in detail the Otto-Hoffmann oven and its condenser-plant. The first authenticated account of an attempt to collect such by-products is in connection with muffle-furnaces stated to have been in use at Sulzbach, near Saarbrücken, in 1768. The first modern form of oven arranged for this was that of Knab, erected in 1856 at Commentry, in the Allier Department, France, and to these ovens a regular condenser-plant was attached. Two years previously, however, fifty ovens of the Powells-Dubochet type had been erected near Saarbrücken, and although in these there was no actual condensation, yet the products of distillation were collected and burnt below the ovens. Carvès modified the Knab oven by heating the sides as well as the base, the width of the oven being at the same time greatly reduced. A number of these ovens were erected. The most important oven-system is, however, that of Otto, with the Hoffmann modification. These are of the modified Coppée type, from 16 to 23 inches in diameter, 5 feet 2 inches to 5 feet 6 inches in height, and about 32 feet 6 inches in length. To an ordinary oven of this shape Hoffmann added a Siemens regenerative chamber for the preheating of the air for the combustion of the gas, the heating of the gas itself being now considered unnecessary. The air in this regenerative chamber is heated to a temperature of about 1000° C. The gas is taken off through the roof of the oven, a portion of the tar and ammonia condensed, the gas then washed with weak

* *Stahl und Eisen*, vol. xii. pp. 818-826, with three plates.

ammonia liquor, cooled, and finally burnt under the oven. With regard to the temperature attained by its combustion, using the graphite-pyrometer of Steinfle and Hartung, controlled by metallic alloys, it was found that the temperature in the channel below the base of the oven varied from 1200° to 1400° , and in the channels at the furnace sides from 1100° to 1200° . In the regenerative chamber at the commencement of the heating of the air the temperature was 1000° , and at the end of the operation 720° . In the stack the temperature observed was 420° . How rapid has been the progress which this oven has made will be seen from the following table, which shows the number of ovens on this system in use in the years mentioned:—

Year.	Number of Ovens.
1884	40
1885	210
1889	605
1892	1205

These details refer to Germany alone. The cost of a block of sixty of these ovens provided with condensing-plant is about £36,000, the ovens without the condensers costing some £15,000.

V.—LIQUID FUEL.

Petroleum as Fuel.—The relative value of petroleum as a fuel is dependent (1) on its market price, and (2) on the method of its utilisation.* With regard to the former of these it may, for the purpose of illustration, be compared with a grade of coal evaporating 8 lbs. of water from and at 212° F. per lb. of coal. The number of heat units utilised would be $966 \times 8 = 7728$. The calorific value of such a coal being about 14,000 heat units per lb. of coal, it follows that the total useful effect was only about 55.2 per cent. A ton of 2000 lbs. of such coal would thus evaporate 16,000 lbs. of water, the cost now being about three dollars, plus the wages of the workmen employed, and this latter cost may for the moment be left out of consideration. With the coal, then, it costs three dollars to evaporate 16,000 lbs. of water. Taking the same degree of efficiency for the oil as for the coal, and placing the calorific value of the oil at 20,475 heat units, 55.2 per cent. of this will amount to 11,303 units, and this divided by the co-efficient of evaporation, 966, gives the number of lbs. of water

* *Iron Age*, vol. I. pp. 102-103, 147-148.

which will be evaporated from and at $212^{\circ} = 11.7$ lbs. of water per lb. of oil. A gallon of oil of the specific gravity of 0.87 weighs 7.27 lbs., and costs about 0.016 dollar. Thus the cost of 187.5 gallons is approximately equal to that of the ton of coal, and 187.5 gallons multiplied by 7.27 lbs. per gallon gives 1363.125 lbs. This number multiplied by 11.7, its evaporative value, gives 15,948.56 lbs. of water evaporated by three dollars' worth of oil. Oil, therefore, at 1.6 cent. per gallon, is practically equal in cost to coal at three dollars per ton, assuming, that is, that the possible useful efficiency of the oil as a percentage of its calorific value is no greater than that of the coal, grate-fired and not used in a gas-producer. The incidental expenses connected with the combustion of the two fuels are then considered, taking a plant of 1000 horse-power at ten hours per day, as the basis of calculation. In the case of coal, $18\frac{3}{4}$ tons of which are burnt, the incidental expenses amount to 21 dollars, or including the cost of the coal the total daily expenditure amounts to 77.25 dollars. In the case of the petroleum this total expenditure is calculated at 60.40 dollars per day, or a saving of 16.85 dollars, as compared with the cost of coal. With a larger plant the difference would be still more in favour of the oil.

The question of the best means of burning petroleum is then considered. In the various burners the oil is usually vaporised by a steam jet or compressed air. The question, however, is not which is the best burner, but which is the best form of furnace in which to continue and complete the combustion. Almost any burner supplemented by a good furnace will give excellent results. In the first place the author considers the placing of one or more burners in the fire-doors of an ordinary boiler front, the grate being covered with fire-brick or some other protective material, there being an unlimited air admission from the ash pit. The flame is usually intensely white from the very nozzle of the burner, is of high velocity, and impinges directly against the bottom of the boiler above the bridge wall, while the mass of incandescent brickwork in the boiler setting is comparatively very small, though highly heated, being confined almost entirely to the portion of the furnace near the bridge wall, and extending but a very short distance beyond this.

Such a method of combustion is both wasteful and inefficient, and leads to the rapid destruction of the boiler, besides the deleterious effect of extreme local heat upon the brickwork of the furnace. There is almost invariably found to be a very rapid deposition of a hard car-

bonaceous material at the point where the primary combination is most intense, and this deposit frequently forms with such rapidity as to necessitate its frequent removal, in order to admit of a sufficient passage for the flame. Much force is required to detach this deposit from the brickwork, which consequently seems to become detrimentally affected. The author next proceeds to consider the theoretical questions connected with the possible temperature obtainable from the combustion of petroleum. The hydrogen it contains amounts to about 13 per cent. of its weight, or at a value for hydrogen of 62,535 heat units, to 8130 units per lb. of oil—a quantity practically equal to the loss due to the carbonic oxide produced, assuming, that is, that the petroleum when burnt yields as the products of combustion water and carbonic oxide. This formation of carbonic oxide, if the gas remains unburnt, leads to the loss of 41.89 per cent. of the total heat efficiency of the oil. Added to this, there is the loss due to that portion of the petroleum which escapes combustion altogether. This latter source of loss may, under certain circumstances, become extremely large, especially if the air supply is inadequate.

The author concludes his consideration of this subject by pointing out that in boiler firing those burners which employ steam for the production of the blast or jet are more convenient and economical than those in which an air jet is employed. The burner should give a spray of very finely divided oil intimately mixed with the steam. It should be possible to ignite this jet by the use of a lighted match, which is impossible if the velocity is too great or the mixture not a thorough one. The burner, too, should be almost noiseless. The method and position of the attachment are also considered, together with the air-supply and the use of regeneration.

There are, according to Mr. J. M. Wilson,* three ways of burning oil as fuel now in use. In the first of these the oil is converted into gas by heating it in retorts, in the second and third it is atomised by jets of steam and air, or by jets of air only. One of the processes which falls under the latter class is described in detail. In this system the oil is lifted by compressed air to the burners, where it is met and sprayed by a jet of air.

In a paper read before the Engineer's Club of Philadelphia, Mr. M. Livingstone † gave the results of some experimental tests with petroleum as a fuel in boiler furnaces. The results showed that for equal

* *Journal of the Franklin Institute*, vol. cxxxiv. pp. 266-278.

† *Iron Age*, vol. xlix. p. 498.

weights the petroleum gave 60 per cent. better results than coal, the theoretical difference in favour of the petroleum being only 45 per cent. The oil was sprayed into the furnace.

The Composition of Petroleum.—Ozokerite is generally held to be a residue formed by the evaporation of the oil. H. Kast and S. Seidner,* in connection with this point and Zaloziński's theory of oil formation from this substance, have investigated some oil residues, and find that ozokerite exists as such in American oils.

The sulphur compounds in oil have been investigated by H. Kast and C. Lagai.† Sulphur is usually present in amounts from 0.136 to 1.87 per cent. A note of the various means of purification is given, and the results obtained on this subject by Messrs. Mabery and Smith are discussed.

Petroleum in Eastern Europe.—In the course of some observations on petroleum in Eastern Europe and the method of drilling for it, Mr. A. W. Eastlake‡ gives a long account of the oil industry of Austro-Hungary, including a good deal of matter not mentioned by Mr. Boverton Redwood§ in his recent paper. The developments of the industry and of the oil territories are dealt with, and a full account is given of the modified Canadian system of boring, with the tools employed. Amongst other details, the logs of some of the borings are given, showing the time and progress of the work, the nature of the strata passed through, and the operations connected with the lining.

Naphtha Industry of Baku.—In a lengthy paper on the condition of the naphtha industry in the Apscheron peninsula, A. Leproux|| gives an account of the history of the development of Baku from the tenth century to the present day. He describes the geological structure of the district and the methods of boring for oil. Finally, he deals with the subsequent treatment of the naphtha, and gives some useful details on the utilisation of the residues of the distillation (*mazout*) for the manufacture of lubricating oils and for heating steam-boilers. A careful consideration of

* *Dingler's Polytechnisches Journal*, vol. cclxxiv. pp. 143, 144.

† *Ibid.*, pp. 69-72.

‡ *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 634-736. four plates.

§ *Journal of the Iron and Steel Institute*, 1892, No. I., p. 337.

|| *Annales des Mines*, 9th series, vol. ii. pp. 117-153, with plate.

the cost of production, transport, and taxes leads the author to the conclusion that the industrial conditions of Baku are unfavourable for Russian petroleum in the struggle with its competitors. The methods of working are not altogether satisfactory, the naphtha is not well received, and there is considerable loss due to overflow and evaporation. The processes of refining and distillation compare unfavourably with those in vogue in America. Moreover, the tenour of kerosene in Russian oils rarely exceeds 30 to 40 per cent., whilst certain American naphthas contain as much as 80 per cent. Lastly, the geographical situation of Baku is altogether unfavourable for a European export trade.

Petroleum in the United States.—Comparative tests of Lima and Pennsylvania petroleum have been made at a steelworks in the Eastern United States. They showed :—

Number of Test.	Oil Used.	Gallons.	Rails Produced, Tons.	Gallons of Oil per Ton of Rails.
1.	Lima	3370	227	14.8
	Pennsylvania	2948	257	12.4
2.	Lima	3052	153	19.0
	Pennsylvania	2935	170	17.2
3.	Lima	3295	165	19.4
	Pennsylvania	2596	192	13.5
4.	Lima	3345	223	15.0
	Pennsylvania	2644	224	11.7
5.	Lima	2460	159	15.4
	Pennsylvania	1981	166	11.9

The Pennsylvania oil, it will be seen, gave much the better results. During the earlier of the tests the results were worse owing to the valves allowing oil to escape.* The large extent to which oil is being used at steelworks in the United States is indicated by the use of 5500 barrels of Lima oil per day at the Chicago Rolling Mill of the Illinois Steel Company.

The Mannington oilfield described by Mr. I. C. White † is situated in Marion and Monongalia counties, West Virginia, on the Monongahela River. In each of the three sections noted at Mount Morris, Mannington, and Fairview, the oil-wells pass through the whole thickness (1900 to 2000 feet) of the Carboniferous system, from the Permian

* *American Manufacturer*, vol. li. p. 26.

† *Bulletin of the Geological Society of America*, vol. iii. pp. 187–216, with map and sections.

series to the oil-sand, the lowest of the Carboniferous strata. The paper contains also a history of the development of the anticlinal theory of reservoirs of oil and natural gas, and of its successful application to the discovery of new sites for oil-wells in the Mannington district.

The geology of the Murrys ville and Grapeville natural gas and oil fields near Pittsburgh is discussed at considerable length by Mr. A. Cummins.*

The South American Oil-Fields.—Up to the present time oil has only been discovered, in South America, in Columbia and Venezuela on the north, and in Chili, Peru, and Venezuela on the west, though traces are said to have been found in Bolivia. The petroleum belt can be traced from eastern Canada to the Gulf of Mexico, through the West Indian Islands to South America. In Cuba and Trinidad pitch is found, and oil has been worked in San Domingo and Barbados. In Columbia but little has been done to develop the fields. The most widely known districts are those of Peru, which are confined to an area of about 250 miles from north to south, and 150 miles wide. There is a considerable likeness to the Pennsylvania oil-field. The oil belt appears to belong to the Tertiary formation, and the first sand rock is met at about 130 feet in depth, being 5 to 10 feet in thickness. Several wells have been sunk at Tumbes, and as they give large quantities of gas, would appear not to have reached the main oil-beds. The oil is rather darker than that of Pennsylvania, and contains less volatile matters, probably since it occurs nearer the surface. Deeper wells have been sunk at Zorritos, south of Tumbes. Lignite has been found at the latter place. Some endeavours have recently been made to further develop the resources. The greatest difficulty at present is the water supply, but several sources might be made available. In December last a well was driven at Tusillal to a depth of 820 feet, when the drill broke. A section of this well is given.† Some oil and gas had been struck, and the bore finished in promising ground. Mr. B. Redwood has reported on the oil from this district, and states that it resembles Baku oil, in that it is practically devoid of solid hydrocarbons.

Petroleum in the Argentine Republic.—According to Mr. H. D. Hoskold,‡ borings to the depth of 200 yards in the province of

* *Engineering and Mining Journal*, vol. liv. pp. 106-107.

† *Engineering*, vol. liv. pp. 475, 531-533, with map.

‡ *Transactions of the Federated Institution of Mining Engineers*, vol. iii. p. 427-433.

Mendoza in the Argentine Republic have resulted in the discovery of petroleum, which is utilised as fuel on one of the railways. A $4\frac{1}{2}$ -inch pipe line has been laid for a distance of $21\frac{1}{2}$ miles. Bituminous shale has also been discovered in La Rioja.

Petroleum in Ecuador.—Though possessing the smallest territory, Ecuador is perhaps the richest in mineral resources of any of the South American republics. Mining enterprise has, however, been practically stifled by legal restrictions. A new mining code, sanctioned on August 15, will probably exert a beneficial influence on the future prosperity of the country. According to Mr. W. H. D. Haggard,* immediately on the passing of this law, a syndicate was formed for taking up the rich petroleum district of St. Helena, on the coast, north-west of Guayaquil. The deposits are very prolific, the geological formation being the same as that of the Peruvian deposits. The oil is pronounced to be of excellent quality, and in view of the advantages offered by the geographical position of St. Helena, the enterprise may in time assume great proportions.

Peruvian Petroleum.—L. Weinstein † states that although deposits of petroleum are known to exist along the Peruvian coast, only in one spot has it been worked to any extent. This place, Zorritos, is in the neighbourhood of Tumbes, in Northern Peru, and the author has submitted the oil obtained there to a careful examination. The first borehole was put down in 1867. Its depth was 146 feet, and the yield was about sixty casks a day. A second borehole was less productive. In 1876 a well was sunk to a depth of 476 feet. At this depth oil-bearing strata were struck, the oil rising to a height of 70 feet above the surface. An accident happened when an attempt was made to pipe the well. The well choked, the oil stream ceased, and no such outflow has since been met with. About forty boreholes have been put down, but without any great success. They are all comparatively close together. The occurrence of petroleum has been observed at many places along the coast. The borings have shown only sedimentary rocks. Bituminous slate and bitumen have also been discovered. The district is absolutely wanting in fresh water. Salt springs occur in many places, accompanied by a blue clay. Much marsh gas escapes from these springs.

* *Reports from Her Majesty's Representatives Abroad.* Miscellaneous Series, 1892, No. 262.

† *Chemiker Zeitung*, vol. xvi. pp. 795-798.

The raw petroleum is thin fluid, and of an agreeable aromatic odour. It is of a brown colour, with green reflected light. By treatment with sulphuric acid and alkali a good reddish yellow oil is obtained, with a bright green fluorescence. The density varies from 0.810 to 0.840. It is extremely rich in readily volatile constituents, and resembles in this respect Pennsylvania petroleum. The analysis of the oil shows it to contain—

Carbon.	Hydrogen.	Oxygen.
84.9	13.7	1.4

The percentages of nitrogen and sulphur are not given. Even at a temperature of 30° C. no solid constituents separate. The author gives a table showing the character of the products obtained at different temperatures, those obtained from other oils being also mentioned for the sake of comparison. The Peruvian petroleum is shown to closely resemble that of Alsace. The volatile constituents possess an agreeable aromatic smell, further purification is consequently unnecessary, and they would be of great use as solvents. The residues could be converted into very viscous and non-freezing lubricating oils. By distillation for illuminating oil, kerosene of the density of 0.824 is obtained, and this has the flashing-point 93° F. The total output of the existing active wells, some twenty-eight in number, has probably in recent years been between 9000 and 10,000 tons, but accurate data are wanting.

Oil in Sumatra.—The Colonial Secretary at Singapore, in a recent report, mentions a new oil-field that has lately become productive. This field lies in the northern part of Sumatra, on the Straits of Malacca. Several concessions over some 320 square miles have been granted, but at present there is only a Dutch company at work producing 15,000 to 20,000 cases per month. The oil is of good quality.*

VI.—NATURAL GAS.

Natural Gas in the United States.—Natural gas has been struck in quantity in Wood County, Ohio, a well, stated to be of the capacity of 1,000,000 cubic feet, having been sunk. Important discoveries of gas have also been made near Elizabeth, and near

* *Engineering*, vol. liv. p. 483.

Kittaning, Pennsylvania; in Westmoreland County, Pennsylvania; near Mount Clemens, Michigan; at the Lancaster fields in North-Western Ohio; near Verona; at Waterford; and at Towanda, Pennsylvania. A well yielding a million cubic feet of gas per day has been drilled near Birdstown, Tennessee; and the most important strike of gas ever made at any well in Pennsylvania was met with on August 2, 1892, in Allegheny County. The gas outflow occurred when the Gantz sand was struck at a depth of 1809 feet. The force of the outflowing gas broke a board from the top of the derrick 70 feet above the end of the pipe, and when only partially closed-in the gas gauge indicated a pressure of 700 lbs. per square inch. A well with a rock-pressure of 500 lbs. has also been brought under control near Saltsburg, Pennsylvania. The gas was struck at a depth of 2015 feet. A well with a rock-pressure stated to reach 800 lbs. has been sunk near Freeport in the same State. Gas has also been met with near L'Anse, Michigan; at Toledo, Ohio, in large quantity in the red shale, and at a depth of 530 feet; near Tiffin, Ohio; in the Washington oil-field, Pennsylvania; and in Ricket County, Tennessee.*

The Pinhook Gas-Field.—A new gas-field has been discovered in the neighbourhood of Pittsburgh. It is twenty miles in length, with an estimated width of four miles. The gas in this field, which is situate fifteen miles from the town, is of high pressure, in some cases indeed so great that it has proved impossible to take the gauges of the wells.†

Natural Gas in Utah.—Mr. J. Wolfe ‡ has examined the neighbourhood of Salt Lake City, Utah. Natural gas is found at a distance of twelve miles to the north of the city, and at the time of Mr. Wolfe's visit there was flowing from two wells that have been put down at this spot in the one case 807,200, and in the other 4,901,700 cubic feet in twenty-four hours, the outflow in the latter well being much less than it might be, as the pipe through which the gas escapes is of small diameter. The quality of the gas is good, and the field is likely to prove a permanent one.

Testing the Pressure of a Gas-Well.—There are three kinds

* *American Manufacturer*, vol. li. pp. 69, 157, 289, 371, 460, 503, 547, 591.

† *Iron Age*, vol. xlix. p. 1226.

‡ *The Salt Lake Times*, July 15, 1892.

of "pressure" observed in gas-wells. The so-called "open-pressure" test consists in placing an $\frac{1}{2}$ -inch pipe with an elbow in the mouth of a flowing well. A small gauge is placed at the other end of the pipe, and the pressure of gas observed is termed its open-pressure. This test is of no value in determining the value of a gas-well, which can only be ascertained by finding the "minute" pressure. This is done by closing a flowing well, and gauging it during the first minute after it has been closed. The "rock" pressure is that shown by the well after it has been definitely closed-in.*

VII.—ARTIFICIAL GAS.

Heat Reactions in the Producer.—A. Naumann † discusses the formation of gas in the producer in relation to the conversion of the heat produced into a form available for subsequent use. In the production of pure water-gas 38,770 calories are absorbed in the reaction between carbon and water, while in the ordinary producer, worked with air, 26,690 calories are produced by the combustion of carbon. This will heat the gas to 2169° C., assuming its specific heat to be constant, and may be utilised if the gas can be burnt at once, but is lost if the gas is stored. There are, however, two means of making use of this heat. It may be used either to decompose water or to decompose carbonic anhydride. By introducing the right amount of these agents, all the available heat may thus be utilised, and if this could be completely done the results would be:—

	Per Cent. by Volume.		
	From Liquid Water at 15° C.	From Gaseous Water at 15° C.	From Carbonic Anhydride
Producer-gas	65.55	57.9	65.3
Water-gas	34.45	42.1	—
Additional carbonic oxide	—	—	34.7

* *American Manufacturer*, vol. li. p. 201.

† *Berichte der Deutschen Chemischen Gesellschaft*, vol. xxv. pp. 556-562.

The gases would have the composition—

	Per Cent. by Volume.		
	From Liquid Water at 15° C.	From Gaseous Water at 15° C.	From Carbonic Anhydride.
Hydrogen	17.2	21.1	—
Carbonic oxide	39.7	40.9	57.1
Nitrogen	43.1	38.0	42.9

The following table shows the number of calories given by the combustion of one litre of the gas, supposing the water produced to be gaseous at 15° C., and also the calculated temperature of the flame :—

	Calories.	Temperature, Degrees C.
Producer-gas	1044	1904
Carbonic anhydride producer-gas	1739	2449
Semi-water-gas from liquid water at 15° C.	1652	2356
Semi-water-gas from gaseous water at 15° C.	1790	2431
Water-gas	2182	2830

Dowson gas formed by blowing steam into a producer is a form of semi-water-gas, whilst the carbonic anhydride water-gas is represented by the system adopted in one form of the Siemens producer, where both steam and a portion of the products of combustion from the furnace is passed through the incandescent fuel. In the above calculations only carbon is dealt with, but the considerations can be applied to fuels containing carbon and hydrogen.

Oil-Gas.—Some researches have been made by Professor V. B. Lewes* on the production of oil-gas from Russian petroleum. The oil used was "distillate oil" of a specific gravity of 0.864. The distillation was carried on at different temperatures, the volume of gas increasing largely with the temperature. The effect of the size of the retort is also shown to be considerable. The nature of the distillation products is discussed.

Fuel-Gas.—The employment of semi-water-gas under ordinary conditions is advocated by Mr. A. Kitson† in the course of a discussion on the relative values of this and other artificial gas. From one ton of anthracite 150,000 to 160,000 cubic feet of this gas should be

* *Journal of the Society of Chemical Industry*, vol. xi. pp. 584-590.

† *Journal of the Franklin Institute*, vol. cxxxii. pp. 424-448.

obtained, averaging 165 heat units per foot, and containing 83 per cent. of the original heat energy. With coal at 12s. per ton the cost may be taken as about $2\frac{1}{2}$ d. per 100 cubic feet. Large pipes may as well be used as small ones when newly laid, so that the extra volume over water-gas is not of much moment, and the gas will burn readily enough, especially if it is pre-heated. The production is simple, and the gas can be made on a small scale. The author has devised a small apparatus for the production of 1500 cubic feet of gas per hour, which has been in use for some time to supply a gas engine. A description of this plant is given.

Professor R. Åkerman's exhaustive paper on gaseous fuel * has been translated into German by H. von Jüptner,† who has detected an error in the calculations in the Swedish original, and the re-calculations this has given rise to, have induced him to publish the translation. The translation covers 121 pages, and is accompanied by twelve large folding tables of figures. The subject is treated under the following heads: Influence of temperature on the specific heat of carbonic anhydride and steam. Production of gas, (1) from wood or sawdust, (2) from peat, (3) from bituminous coal. Comparative observations of the progress of gas production from various fuels. Conditions of heat in the production of gas. Methods of effecting the calculations. Comparisons of the distribution of heat in the production of gas from various fuels. Calculation of the amount of heat lost through the walls of the producer by radiation and conduction. Influence of the rate of charging on the quality of the gases. Pyrometric heat of the gases. The relative gas-producing values of various fuels. Gas-producers, drawings of the gas-producers employed in the investigation being appended. The condensation of water and tar. Calculation of the water condensed. Calculation of the time occupied by the gases in the actual condensing area. Calculation of the amounts of heat absorbed by the cooling water. Calculation of the amounts of heat yielded by the gases in their cooling to 0°, as well as in the cooling effected by the condensers. Comparative considerations of condensers and their efficacy. Comparisons of the amounts of heat yielded by the gases and those absorbed by the cooling water. Considerations of the extent of the action of condensers. The most important conditions on which the efficacy of condensers depends. Lastly, the conditions under which condensation should be employed.

* *Jernkonterets Annaler*, vol. xlv. pp. 321-462.

† *Berg- und Hüttenmännisches Jahrbuch der k.k. Bergakademien*, vol. xl. pp. 81-203.

The folding tables illustrating the text are as follows: 1. Data relating to gas-producers employing wood or sawdust. 2. Weight and composition of various kinds of wood and sawdust. 3. Results obtained with gas-producers in which peat is employed alone or in admixture with wood and bituminous coal. 4. Weight and composition of various kinds of peat. 5. Weight and composition of various coals. 6. Results of several experiments on the dry distillation of peat on a large scale. 7. Yield of tar from gas-producers. 8. Results obtained with gas-producers employing bituminous coal. 9. Composition of fuels and of the gaseous products of combustion obtained from them. 10. Production of gas from various fuels. 11. Distribution of heat in the production of gas from 100 kilogrammes of fuel. 12. Results obtained with various condensers.

The illustrations elucidating the text include drawings, to the scale of 6 feet to the inch, of the gas-producers of Domnarfvet, Falun, Bofors, Boxholm, Lotorp, Munkfors, and Kolsva.

Analyses of Producer-Gas.—R. Åkerman * gives the following analyses of producer-gas obtained from the substances mentioned, the percentages being given by weight:—

	From Wood.	From Sawdust.	From Peat.	From Coal.
CO ₂	11.5	15.1	12.1	3.6 to 11.9
CO	28.4	26.1	27.2	24.1 „ 32.6
C ₂ H ₄	0.6	0.3	0.4	0.2 „ 0.7
CH ₄	2.9	2.3	2.7	1.9 „ 3.1
H ₂	0.5	0.8	0.9	0.5 „ 0.8
N ₂	56.1	55.4	56.7	60.0 „ 62.1
Totals	100.0	100.0	100.0	...

The coal used in the producers contained—

	Per Cent.
Carbon	68.7 to 77.1
Hydrogen	4.7 „ 5.3
Oxygen	8.8 „ 11.9
Nitrogen	1.1 „ 1.3
Sulphur	0.4
Ash	4.0 to 7.5
Water	2.1 „ 7.6

The author considers † that the rate at which the producers may be

* *Berg- und Hüttenmännisches Jahrbuch der k. k. Bergakademien*, vol. xl. pp. 94, 101, 106, 114, 116.

† *Ibid.*, pp. 152-155.

driven depends rather on physical than on chemical conditions. Rapid working can be employed with advantage as long as there is a sufficient balance of residual heat to cause the formation of carbonic oxide, for which purpose a considerable amount of heat is required. With regard to the percentage of water that can safely be present in wood to be utilised in the producer without lowering the heat of the gas produced, this cannot well be permitted to exceed 26 or 27 per cent. If it exceeds this the gas temperature will not be more than from 70° to 85°.

An Improved Producer-Gas System.—In the system adopted by the Chicago Heat Storage Company a boiler-plant of 100 horsepower or less requires the service of but one man. The producers employed are of the shaft type with air-jacketing. The gas is taken direct to boiler furnaces. The producer grates are of novel form, consisting of sloping fixed side-bars, and a movable horizontal grate in the middle. The fuel forms a bed of at least 4 feet in thickness. A mixed steam and air jet is employed. A regenerator system is also used in connection with the combustion of the gas in the boiler furnaces.*

New Forms of Gas Furnaces.—Drawings are published of various forms of furnaces adapted for the combustion of the Loomis producer-gas. These furnaces have been erected at the works of the American Tube and Iron Company of Middletown, Pennsylvania, and the drawings published include a forge, reheating furnace, billet heating furnace, and a double-hearth puddling furnace. In each of these furnaces the main points lie in the arrangements for the intimate admixture of air and gas, supplied at an even pressure, before their entrance into the furnace; the burning of the gas in the apparatus where the work is to be performed; and the utilisation of the waste heat in pre-heating the air to be used for the combustion of the producer-gas. The furnaces are mostly circular in shape.†

Sheel's Gas-Producer.—Mr. J. W. Sheel ‡ describes his producer as consisting of a wrought-iron brick-lined casing, into which, near the bottom, is built an annular cast-iron blast-box furnished with a loose grate. The fuel is charged through a bell and hopper, and the

* *Iron Age*, vol. xlix. pp. 760-762, five illustrations.

† *Ibid.*, vol. xlix. p. 246, eight illustrations.

‡ *Proceedings of the South Staffordshire Institute of Iron and Steel Works Managers*, 1891.

incandescent bed rests partly on the blast-box and partly on the grate, which can be lowered to release clinker. The air is blown in by a steam-injector.

The Use of Gaseous Fuel.—In his presidential address to the Society of Chemical Industry, Professor J. E. Reynolds * discusses the modern developments in regard to fuels and their uses, especial attention being paid to coal, peat, and petroleum. The present production of coal is 485,000,000 tons, of which the United Kingdom contributes 182,000,000 tons annually, and at this rate the era of dear coal cannot be far distant. Some advances in economy have been made, such as in the use of the gas-producer, especially when making water-gas. It has been proposed to make two qualities of gas, one for heating and one for lighting purposes, but this seems to be impracticable for general adoption. Another plan is to make gas of low illuminating power, and to enrich it at the point of consumption, but the true solution will be found in a compromise between the various systems. The utilisation of peat is of special interest to Ireland. In its natural state it is difficult to use, but attempts have been made with partial success to compress it, and also to partially carbonise it, but the cost of the preparation is large in spite of many statements that have been made. There is more prospect of success if the peat is gasified, and the author has devoted some attention to the use of the Siemens producer for this purpose. As an outcome of this, a regenerative gas furnace for working up scrap iron at the engine-works at Inchicore has been erected. The furnace was supplied with peat containing 38 to 40 per cent. of water, and no difficulty was found in maintaining the requisite temperature. It has been proposed to gasify the peat at the centre of production, and to convey the gas by pipe lines, and the suggestion seems feasible. Petroleum, weight for weight, is more efficient than coal, but the chief reason why it is so valuable is the ease with which it can be gasified. The rise and progress of the petroleum industry are described, and figures are given to show the advantages of using this fuel. It thus becomes evident that if a fuel is to be used economically and conveniently, it must be completely or partially gasified. Petroleum lends itself most easily to this treatment, in addition to which it may be used in conjunction with gas made from coal or peat.

* *Journal of the Society of Chemical Industry*, vol. xi. pp. 571-577.

VIII.—*COAL-MINING.*

Shaft-Sinking in Quicksand.—A description has been published* of some of the new shaft sinkings in the North of France. The first of these is the No. 10 pit of the Lens Colliery, where the Poetsch system is in operation. The toughness of the stone below the upper fissured chalk is about that of gypsum. Small powder charges were being used, and the rate of progress was about 3 feet per day. Electric light is used in the shaft. At the Lièven Colliery, one shaft has recently been sunk, and another is being put down, on the Chaudron system. A modified form of tubbing has been employed, the moss-box being dispensed with, and its place being taken by a broad flange on the bottom ring and concrete filling.

Near Nuneaton two shafts are being sunk under considerable difficulties as regards water. Evans pumps have been installed, and the sinkings are proceeding. A description of the method of slinging the pumps and of the work at the shafts has recently been given.†

A process for dealing with quicksands has been devised by Mr. R. L. Harris,‡ and consists in solidifying or forming partitions in the sand by means of cement, which is injected with the aid of water. Pipes are sunk to the desired level, and a current of water is forced down one or more of the pipes, whence it flows to and up the others, thereby washing out a channel in its line of flow. By repeating this operation chambers are formed in the running ground, and these chambers are then filled with cement grout under pressure. In this way a floor can be formed between the pipes, and also vertical walls, besides which the grout penetrates and solidifies the surrounding material. This process has been carried out with considerable success in building a large sewer through quicksand, and there appears to be an extensive field for the application of the method.

The Haase and the Haeuser systems of sinking shafts in very wet ground are described by M. Herold.§ These have been employed at the Zwickau lignite mines. Here there are two thick seams of lignite, above which lies a thickness of from 40 to 50 yards of alternating beds of clay and sand. After sinking in the ordinary manner to a depth of

* *The Engineer*, vol. lxxiii. pp. 112-144.

† *Ibid.*, p. 483.

‡ *Engineering News*, New York, vol. xxvii. pp. 420-421, with illustrations.

§ *Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen auf das Jahr 1891*; through the *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. p. 321, and illustrations.

nearly 28 feet, a rapid increase in the water to be pumped was encountered, and this increased to such an extent that finally, at a depth of 44 feet, another method of shaft-sinking became necessary. It was, therefore, decided to adopt the Haase pipe system. The Haase 4-yard pipes were consequently put down, and an attempt was then made to continue the sinking inside this system of pipes, but the inflow of water was too great. An additional 6 feet of pipe was then lowered below the main system, but this proved of no avail. The engineer in charge, Mr. Haeuser, then decided to adopt another method. This consists in employing corrugated plates of sizes varying with the dimensions of the shaft to be sunk. The main system of plates put down, like the pipes in the Herold method, is 6 feet 6 inches in depth, a second length of 3 feet 3 inches being inserted below the main system. The corrugations of these plates slide into each other, and the connection can be made with ease and completeness. When putting these sheets down, water-pipes were placed inside the corrugations, much as these are used in the other system referred to. Using this method, the shaft was soon sunk to the required depth.

Sinking a Deep Shaft at Witkowitz.—M. Jicinsky * describes the sinking of a shaft at the Rothschild collieries at Witkowitz. This shaft has been sunk at a distance of over 2000 yards from the nearest existing shaft, thus giving 1000 yards on either side to be served by this one shaft. It is in reality a double shaft, each shaft being circular in form. Iron tubbing has been employed. The winding-shaft has an internal diameter of 16 feet 3 inches, and the upcast shaft, 45 feet away, an internal diameter of 13 feet.

Winding by Water-Balance.—The plant that has been installed at the Ynis-Merthyr Colliery for winding by the aid of a water-balance is described by Mr. M. W. Davies.† Considerable developments have recently taken place at this colliery, where the major portion of the coalfield is separated from the old workings by a downthrow fault of 40 yards. Sufficient water comes from the old workings to furnish power for winding from the lower part of the seam, so it is dammed back and conveyed to the pit head by a 6-inch pipe, and there em-

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 201-204, with illustrations.

† *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 746-749, one plate.

ployed for filling balance-tanks under the cages. An endless winding-rope is used. It passes over a large pulley on the head-gear, and it was originally intended to make this pulley so large that the ropes would have to be brought into the usual lines of the cages by guide-pulleys in order to obtain a good grip on this pulley. This plan was, however, not adopted, as a pulley large enough could not be readily obtained. At the bottom the rope passes round a tension pulley. Sufficient water is admitted to valve tanks under the cages to raise the coal, an average of 24 cwt. being required. The depth of the shaft is 25 yards, and the appliances are estimated as equal to landing 400 to 500 tons daily.

Inclines or Shafts for Coal-Mining.—Mr. W. Duncan * discusses the advantages of inclines or slopes over shafts for the purpose of mining coal. As the advantages of slopes the following points are mentioned:—smaller cost of opening; less height to lift coal and water; one pair of engines only required instead of two; less liability to wreckage; coal may be worked sooner, and can be more readily taken out; less water to be raised, as the old workings may fill; and greater rapidity of opening up.

Devices for Preventing Overwinding.—A. Kas † observes that of the hundred and one cases in which the winding-rope or chain broke in the kingdom of Saxony between the years 1884–1891, it was proved that no less than twenty were due to overwinding. In consequence it was ordered in 1890 that at those Saxon mines where men are continually being hoisted or lowered in cages, some safety device should be introduced by which, in case of overwinding, the steam would be automatically shut off and the cage brought to a standstill. Automatic signals were also suggested, and the author describes two newly-devised mechanical arrangements for throwing the engine out of gear in case of overwinding, steam being shut off and the break applied.

Winding at the Marles Collieries.—M. J. Doury ‡ states that the arrangements at one of the shafts at these collieries have recently been modified, in view of the necessity which arose to meet an increased

* Paper read before the Western Pennsylvania Mining Institute, Pittsburgh, 1892.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 407–411, with illustrations.

‡ *Génie Civil*, vol. xxi. pp. 67–71, with eleven illustrations.

output. The wooden guides were replaced by iron ones, and the flat (aloe) cable by an endless one, on the Kœpe system, as modified by Mot. Using this with constant velocity, this velocity may be maintained at an exceedingly high maximum. The modification of the Kœpe system that has been adopted consists in doubling the haulage cable, and also the tail-end of the cable. Each of the two haulage cables is in itself sufficient to support the cage, so that a high degree of safety is attained. The description is accompanied by illustrations showing the arrangements adopted.

Safety-Cage for Mines.—Mr. J. Whitelaw * describes a safety-cage for mines. The cage is suspended by rods attached at their upper ends to a safety-hook or disengaging device on the end of the winding-rope, and at their lower ends to pivoted levers on each side of the cage. In case of breakage, blade-springs draw up the inner ends of these levers, which are formed with teeth adapted to bite into the guides. Two cages of this form have been under the author's charge for several years.

Winding-Engines.—A two-page plate of the winding-engines built for the East Elliot pit of the Powell-Duffryn Colliery is given in *Engineering*,† together with some detail drawings. The engines are designed to raise 1400 tons per day. The cylinders are 42 inches in diameter by 6 feet stroke. The drum is 24 feet in diameter, and it carries 9 tons 4 cwt. of rope; two cages with their chains, 5 tons 4 cwt.; tubs, 19 cwt.; and coal, 2½ tons per lift. The engines are of the simple type, having valves worked by a rocking lever and governor trip gear cut-off. Allan straight-link reversing-gear is applied and a steam brake.

Underground Rope-Haulage.—Very full details are given of the underground haulage by endless rope at the Ansley Hall Colliery by Mr. W. G. Philips.‡ The pits are sunk to a depth of 168 yards, intersecting the Rider coal at a depth of 68 yards. From the bottom of the shaft an incline is driven to the deep, cutting the Rider coal at 325 yards from the pit bottom, where the measures lie at 25°. To

* *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 728-734, one plate.

† Vol. liv. pp. 414 and 478.

‡ *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 847-854, two plates.

reduce the gradient, an incline to open out the deep coal has been driven to the side of the dip and the levels driven out from the bottom. This incline is 480 yards long. The seam is worked on the longwall system. Haulage is done by an endless rope, driven from engines at the surface at 2 to $2\frac{1}{2}$ miles per hour. An 8-foot C driving pulley with movable rim is used. Steel rollers every 15 yards keep the rope off the ground, and at a heavy curve at the head of the incline vertical steel rollers are placed 21 inches from centre to centre. Plates instead of points are used at the junctions. The clip, which has been in use for five years, consists of two side plates, fulcrumed on a bolt, and caused to grip the rope by means of a wedge-ended lever pivoted between them. Steel flange rails of 30 lbs. to the yard are used. The tubs carry 8 cwt., and 480 tons are hauled in $8\frac{1}{2}$ hours. The haulage-rope works a pump at the bottom of the incline. Drawings are given to show the general arrangement of the plant and its details.

The haulage at a thin seam colliery in West Yorkshire is described with the aid of a plan by Mr. J. Nevin.* The seam averages 28 inches in thickness. The trucks weigh 2 cwt. and hold 5 cwt., and run on a line with a gauge of 23 inches. There are two drawing-pits, with an output of 400 tons to 475 tons daily. Steam at 50 lbs. pressure is taken down the shafts to four engines, and full details are given of the various inclines worked. The average dip of the seam is $2\frac{1}{2}$ inches per yard, but there are numerous faults crossed by stone drifts at a gradient of 6 inches to the yard. Both endless rope and endless chain haulage are used. Chain haulage is found most convenient when there are quick changes of gradient, but when the planes are moderately flat, endless rope is better, on account of its less weight. Details of the cost of haulage and roading are given.

In connection with the breakage of a steel wire rope on an incline, 1275 yards long, and weighing about $2\frac{1}{2}$ lbs. per yard, M. Jacob † discusses the subject of haulage generally. The rapid deterioration of wire ropes through using them on too small pulleys is dealt with, the effect on the rope as a whole, and on the separate wires being pointed out.

Electric Haulage.—The electric haulage plant at the Cannock and Rugeley collieries is described by Mr. R. S. Williamson.‡ An old

* *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 507-510.

† *Annales des Mines*, 9th series, vol. ii. pp. 97-106.

‡ *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 483-485.

winding-engine is used to drive an Elwell-Parker shunt-wound dynamo, giving 200 amperes at 300 volts when running at 400 revolutions. The motor is of the same size as the dynamo but series-wound, and will give 64 brake horse-power. The copper cables are $\frac{37}{11}$, highly insulated. A simple water-resistance is used. The machine at present is hauling 300 tons per day over a distance of 583 yards with gradients from $\frac{3}{4}$ inch to 2 inches per yard, but the distance will be increased to 810 yards with gradients of 9 inches. The inclusive cost is given as £1187, as compared with £1440 for air-compressing plant. The useful effect is 65 to 70 per cent.

Mr. W. Wardle* describes the plant at the West Cannoek Colliery. A Goolden dynamo, capable of giving 48 electric horse-power at 550 volts, is used. The current is conveyed through a $\frac{1}{2}$ cable, well insulated for a distance of 1400 yards from the shaft bottom. The cost of the plant is given as £1000, and that of a compressed air plant as £2156. The general arrangement of the plant is shown on a plate accompanying the paper. Both Mr. Williamson and Mr. Wardle would prefer direct rope-driving plant to electric power if possible.

Electric Mine Locomotives.—C. Bailey† describes the adoption of electric locomotives at the No. 4 pit of the collieries at Marles in the Pas-de-Calais. The dynamo supplies current both for lighting and haulage. In the mine the conductors are of copper 0.35 inch in diameter and well insulated, and are connected to flange rails on which the collecting trolleys run. The locomotive is 7.54 feet long, 2.94 feet broad, and 4.92 feet high. Its weight has been brought up to about 2.3 tons to insure adherence. The motor is designed to give ten horse-power, and is arranged with its axis parallel to the track. A rheostat is placed in the circuit. A large number of experiments have been made to determine the power required with the engine running light and with various loads. These experiments prove that the gradient in the road should be uniform, if a uniform current be required. With a light load the efficiency is low, as much is lost in useless resistances, but it is better to increase the speed rather than the load. The best results were obtained with a load of twelve empty tubs at a speed of $11\frac{1}{3}$ feet per second, but this speed was too high. When drawing fifteen tubs, or a total load of 2.37 tons at a speed of 7.8 feet per second, the efficiency was 58.50 per cent.

* *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 486-494.

† *Revue Universelle des Mines*, vol. xix. pp. 107-125.

An electric locomotive designed for a roadway as narrow as 32 inches in parts, and running on a 22-inch gauge, is illustrated.* The motor is arranged parallel to the rails and drives through bevel gearing. The motor framework is hinged on one pair of axles and borne by springs on the other. Current of 200 volts is used, being reduced by a motor transformer from 500 volts. The road is 1200 yards long, and the current is supplied through two overhead conductors. The motor is series-wound, and develops 15 brake horse-power at 1000 revolutions.

An illustration † is given of an electric locomotive designed for mining work. It is built for a 30-inch gauge and its dimensions are: length, 9½ feet; height, 3 feet; and width, 4 feet. It will run at six to ten miles per hour. An iron-clad ring armature is used, and it transmits motion to the driving-shafts through two intermediate shafts on opposite sides of the motor shaft. Connecting-rods are omitted to decrease the width, and to permit spring suspension and outside axle-boxes. The trolley is mounted so that it can easily be transferred from one end of the locomotive to the other.

Steel Trucks in Belgian Collieries.—In the Belgian collieries, trucks made entirely of metal have been in use for several years. Drawings of these trucks, published by P. Vanhassel,‡ show that repairs are cheaply and easily effected. A damaged part has merely to be unriveted and replaced by a fresh one kept in stock. The damaged part is, as a rule, merely bent, and, being of steel, can be straightened and used again. A truck of this type can be put together without difficulty by a lad, the separate parts having been purchased. A truck with a weight of 375 lbs. and a capacity of 336 lbs. of coal costs £2, 6s.

In many Belgian mines, the wheels of the truck are loose and turn freely on the axle, the advantage they present being the small resistance they offer in passing round curves. The wrought-iron axles are square in section with 1·38-inch side. Four wheels and two axles weigh 132 lbs. and cost 19s. 9d. The entire truck weighs 507 lbs. and costs £3, 5s. 9d. The weight of the truck is to that of the coal carried as 1 is to 2·3, and this may be considered a very favourable ratio. A truck of the old type with wooden body weighed 551 lbs.

* *Colliery Guardian*, vol. lxiv. p. 386.

† *Engineering and Mining Journal*, vol. liv. p. 321.

‡ *Revue Universelle des Mines*, vol. xvii. pp. 294-299.

and cost £3, 8s. By the introduction of trucks with steel bodies the output of the Mariemont mine has been increased 40 per cent.

Keeping Open Haulage Roads.—Mr. W. H. Chambers* describes the methods adopted for removing the posts of coal along the main haulage roads at the Tankersley collieries. The coal is here worked on a modified longwall system, leaving posts from 20 to 40 yards thick on each side of the main road. The shaft is 100 yards deep, and from it there is an incline about 1000 yards long, with a travelling road parallel to it, and 10 to 12 yards of post between them. On either sides of these roads posts 25 to 30 yards had been left. From the bottom of this incline levels have been driven some 800 yards or more, with posts in the main part of their lengths. There is also a second incline. In the main incline and levels there is a double line of rails with endless over-rope haulage. As the weight was coming on, owing to workings in another seam, and as the coal in this seam was becoming worked out, it was necessary to take some steps to keep these roads in good condition. Three methods were adopted. In the first of these, the low side posts were taken out from the far end, keeping the packing well up to the coal. A ripping of 3 feet supplied packing material. After about six months the top side was taken out in 40-yard pieces, and another ripping of 3 feet made to supply packing. Steel bars were set where the roof required it, and the work was done without stopping the haulage. In another level the top side was taken out first. In the main incline, 6 or 8 yards of coal on each side was first taken out, 3 feet of the roof ripped down, and a pack 4 yards wide put in. Then the other portion of the coal was worked out 25 yards behind in bank form. In the second incline, the whole of the coal was taken out at once in several places.

Modern Explosives and Firedamp.—J. Mauerhofer† observes that for many years past constant experiments have been made at the collieries of the Kaiser Ferdinand's North Railway, with a view to reducing as far as possible the dangers arising from fire-damp. The author states that these experiments resulted in the introduction into use at these collieries of "fire-damp dynamite" as the explosive, with a friction fuse. Coal-dust, as is now well known, possesses the property

* Paper read before the National Association of Colliery Managers, Leeds, April 30, 1892; *The Colliery Manager*, vol. viii. pp. 86-87.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 507-510, and 517-522.

of rendering explosive gas mixtures containing less than 2 per cent. of gas. To avoid such gas accumulations, the author states that at a colliery near Aix-la-Chapelle an attempt was made to exhaust the gas from the coal by a series of pipes with a suction attachment, but the experiments were wholly unsuccessful. Then, as it was found impossible to exhaust the gas from the coal, efforts were made to render the coal-dust as inexplorable as possible. The air sent into the colliery was therefore completely saturated with moisture, but the danger from suspended coal-dust was found still to exist, notwithstanding this saturated condition of the mine atmosphere. Direct sprinkling was then adopted. The quantity of water used proved to be immense, a gas-burner jet 0.04 inch in diameter using 1.3 gallon of water per minute. The pecuniary side of the question proved not to be an unimportant one. Sufficient water is now used to wash away the mud produced, as even a very complete damping of the dust is not sufficient to render it completely free from danger. Yet even though it were possible to remove the greater part of the dust in this way, there would still be spots which it would be practically impossible to keep permanently free from dust. It was consequently seen that the arrangements made were not in themselves sufficient to render the collieries safe. Attention was therefore next directed to the arrangements for shot-firing, efforts being made to find a substitute for this practice. Lime cartridges were tried, but the results were not of a satisfactory character; next came the hydraulic wedge of Levet, and then came other mechanical devices, notably those of Brunton, Schramm, and of François and Dubois, the last of which is still in use in the fiery mines of the Liège coal basin. A more modern device, that of Franke, is now being tried. The results obtained with lime cartridges and with the Levet wedge could not compete financially with those resulting from the use of powder, and explosives had consequently to be again resorted to. At this time, 1887, a prize of 1000 ducats was offered in the Ostrau Karwin district for the best method of replacing shot-firing in fiery mines, and of the 231 proposals sent in it was considered that the best results were likely to be obtained by using the Lauer friction fuse, by using a water-casing for the cartridges, or by employing the Walcher coal-breaker. Since 1887 the explosives themselves have obtained the most attention. Shattering explosives were shown to be incapable of being utilised with safety in fiery mines, and the so-called safety dynamites have been introduced. Where shattering explosives have to be employed, then the water-cartridge

deserves attention. Unfortunately these cartridges require much care in charging and in use, and the rough hands of a workman are not adapted to their manipulation. Next Galloway proposed to replace this water-casing by one of some other material, such as moss, which would hold in suspension considerable quantities of water. This, in turn, gave way to the use, not of water in mechanical mixture, but of water of crystallisation, and Müller adopted a mixture of crystallised sodium carbonate with the explosive. This led to the two main divisions of modern explosives—the ammonia and the soda safety dynamites. In the collieries to which the author more particularly refers the soda safety dynamite is alone employed. The introduction of a safe explosive only partially solved the difficulty, the fuse and detonator also requiring attention as the possible causes for explosions. It was also necessary to adopt a method of firing the charge within the bore-hole. This is possible either by the electric, percussion, or friction methods, the last being the best. The author gives details showing that the failures in this Lauer friction method only amount to 0.62 per cent. in 419,370 cartridges. In the great majority of the failures the wire was pulled out together with the friction attachment, no explosion following. This has as its cause the hygroscopic nature of the friction charge, which, owing to this, loses its explosive character. It is necessary, therefore, to keep these friction igniters in places very free from damp. The author gives details as to each of a number of slight accidents which have occurred when using this igniter, but in nearly every instance the carelessness of the workman was the sole cause of the accident. As a result of all the experiments carried out at the collieries of the North Railway referred to, these friction igniters, in combination with safety dynamite, are now alone in use for bringing down the coal.

Tests of Explosives.—E. Larmoyeux and L. Namur* give the results of an extended series of tests made with various explosives, principally to determine the influence of temperature and of the length and kind of tamping. The tests were made with several samples of grisoutite, compressed powder, and Favier powder. The tabulated results show the weight of the explosives used, the detonator, and the strength of the explosive as measured by projection and by the lead block. The experiments in the presence of fire-damp and sus-

* *Annuaire de l'Association des Ingénieurs sortis de l'Ecole de Liège*, 5th series, vol. v. pp. 77-120.

pended coal-dust with these explosives are also tabulated, to show the weight of explosive and detonator, the length of tamping, the amounts of dust and gas present, the temperature and the results. A large number of explosives were also tested by being submitted to a falling weight.

New Explosives.—F. Gabaston * refers to the recent experimental work of Berthelot and Tarpin with fulmenite. The results obtained by its use show it to be incomparably more powerful than dynamite. An explosion of fulmenite shattered the rocks surrounding the bore-hole to such an extent that the débris after the explosion could all be removed by hand. It is perfectly safe in transport, does not freeze or exude, and is not injured by prolonged contact with water.

Herculite, an explosive invented by A. Pallé,† is stated by him to be more powerful in its action than all other nitro-glycerine explosives. It is a yellowish-grey powder, and is stated to be made of sawdust, camphor, potassium nitrate, and certain other materials, details of which are not given.

Dynamite Fumes.—P. F. Chalon ‡ refers to the influence exerted by the fumes resulting from the use of dynamite for blasting purposes on the health of the miners employed. The approximate composition of these combustion products is as follows :—

	Per Cent.
Water vapour	19
Carbonic oxide and carbonic anhydride	58
Nitrous products	15
Nitro-glycerine vapour	variable

About 1105 gallons of carbonic oxide and 300 of carbonic anhydride are liberated by the combustion of 1 lb. of nitro-glycerine, considering the gases as having the temperature of the explosion. It is evident that the atmosphere of a heading must be very seriously affected by such a large inrush of deleterious gases. The result of the respiration is nearly always the same: headache, coughing, indigestion, and nervous troubles. Those workmen who are the most subject to neuralgia, dyspepsia, and headache, are the ones who suffer most readily. Acute cases are rare. Dr. Darlington has shown that these are accompanied by nausea, vomiting, a violent and irregular action of the heart, a feeble and intermittent pulse, and general appearances of

* *Génie Civil*, vol. xxi. p. 95.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xi. p. 301.

‡ *Génie Civil*, vol. xxi. pp. 87-88.

asphyxia and poisoning. Strong coffee, inhalation of ammonia, sulphurous acid, and a little acetic acid are used as remedies. Some ammonium carbonate and antipyrine should be given internally. But, above all, prevention being better than cure, great care should be taken to clear the headings of the products of the explosion before the workmen are allowed to return.

The Best Form of Safety Fuses.—M. Janet * gives an exhaustive description of the methods of igniting safety-fuse to render it safe in fiery mines. Firedamp may be ignited by safety-fuse burning at the rate of one to one and a half yard per minute in any of the following ways: (1) By the incandescent substance used to light the end of the fuse; (2) by sparks from the end of the fuse; (3) by explosions in the fuse itself; (4) by the combustion of the explosive before its explosion. The danger arising when the last method is adopted can only be obviated by employing skilled men, and by taking care that the fuse is not inserted too far into the cartridge. The danger associated with the third method is due to large grains of powder in the fuse, only to be avoided by carefully sifting, and by increasing the strength of the covering. White fuse is preferable to tarred fuse. It is generally believed that German tinder will not ignite gas, but no direct experiments appear to have been made. Igniting the tinder through the gauze of a lamp is, however, dangerous, and so are the sparks given off from the end of the fuse in this method of lighting. Sufficient safety is, however, probably afforded by allowing about 4 inches of the fuse to burn before its end is exposed. This length may be determined by counting the seconds required, or by the touch when the heat is felt in the fingers holding the fuse. To insure safety in this way the fuse should be enclosed in a chamber, which may be of wire gauze. These devices are of two classes. The first are used once only, and permit the fireman to retire slowly; the others are used over and over again, and these are inferior, as far as safety is concerned, as the man is tempted to retire too quickly. Several of these appliances are described by the author. In 1881, M. Lagot proposed the use of a coal impregnated with saltpetre, burning without flame, and placed in a chamber into which the fuse is inserted. Bickford's safety igniter † is then described. In this sulphuric acid is brought into contact with chlorate of potash and

* *Annales des Mines*, 9th series, vol. i. pp. 351-371.

† *Journal of the Iron and Steel Institute*, 1891, No. I., p. 321.

sugar, enclosed in a tin tube on the end of the fuse. The acid is contained in a glass capsule, which is broken by a special pair of nippers. This device has been used successfully in several French collieries.

Devices of the second class are also freely in use. In one form the fuse is enclosed in a barrel, and is fired by a percussion-cap. Johnson and Howat's safety-lamp has been favourably reported on by the French Explosives Committee. In this the fuse is introduced into the lamp through a tube, and is fired by a kind of pricker wire. Another device is the Bourdoncle * fire syringe, in which tinder is fired by the sudden compression of air.

The Detonation of High Explosives by Percussion.—Mr. W. J. Orsman † has made some experiments to determine the effect of percussion on various explosives, and the difference between detonation and the explosion produced by percussion. Explosives may be arranged in the following three classes, the first requiring a detonator with 15 grains of fulminate of mercury and the third needing 30 grains :—

- I. Nitro-glycerine compounds, comprising dynamite, gelignite, blasting gelatine, carbonite, &c.
- II. Nitro-cotton, including cotton powder, tonite, &c.
- III. Nitrate of ammonia powders, including roburite, ammonite, &c.

Percussion experiments with a falling weight of 59 lbs. pointed at the lower end, exploded substances of the first class with a fall of 6 to 12 inches, of the second class with 2 to 3 feet, but with falls up to 40 feet the latter class explosives were not exploded but only decomposed locally. The explosion of roburite by a detonator did not ignite gunpowder.

Friction Igniters in Fiery Mines.—J. Lauer, ‡ after referring to the main causes of explosion in fiery mines, states that he formed the opinion that to avoid such explosions it was necessary (1) to have only one central method of ignition in the charge inserted into the drilled hole; (2) to use a shattering explosive; and (3) not to use too heavy a charge. Electric firing is too complicated for ordinary work, and the author therefore devised his now well-known friction

* *Journal of the Iron and Steel Institute*, 1891, No. I., p. 320.

† *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 574-579.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 177-189. See *Journal of the Iron and Steel Institute*, 1892, No. I., p. 357.

arrangement. In conclusion, he discusses the objections which have been raised as regards his method of firing.

Coal-Cutting Machines.—The Brown coal-cutting machine is one of the chain-cutter type. The chain is carried by a frame which is advanced into the face of the coal, and the chain runs in a horizontal plane on this frame, so that the cuttings are brought out at the side instead of underneath, as in those machines which work with the chain in a vertical plane. The power is derived from an electro-motor mounted on the machine, which drives the chain directly through a sprocket-wheel and also drives the screw-feed gear.*

An illustration is given † of the Ednie coal-cutting machine, in which the undercutting is done by a number of drills carried by a slide working at right angles to the face. An electro-motor is used to drive the machine.

A rotary electric coal-drill, made by the Thomson-Houston Company, is illustrated.‡ An adjustable standard carries the combined motor and drill driving mechanism.

The Longwall System of Working Coal.—Mr. W. S. Gresley § describes the longwall system of working coal, and points out the conditions under which it is best applicable. These are as follows:—Where all the coal is to be mined; where lump coal sells best; generally in seams under 6 feet in thickness; where much dirt or refuse is contained in the coal, or has to be mined with it; where economy in timber is necessary; where concentration of work is desirable; in fiery seams where the fresh air current should sweep the face; where blasting is troublesome; where black damp and bad air are present; where division of labour is desirable; when it is required to get the best return from coal-cutting machinery; where top and side weights are much felt; in thin and in steep seams; where a steady sale obtains; where it is desired to let down the surface as evenly and regularly as possible; in very thin flat seams; where plenty of skilled labour can be obtained; and, lastly, where rapid opening-up of workings for large outputs is desired.

Pumping Appliances.—Mr. W. H. Chambers || gives an account

* *Engineering and Mining Journal*, vol. liv. p. 275.

† *Ibid.*, vol. liv. p. 249.

‡ *Ibid.*, vol. liv. p. 202.

§ Paper read before the Western Pennsylvania Mining Institute, Pittsburgh, 1892.

|| *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 513-518, two plates.

of the pumping appliances used in the sinking operations at the Cadeby new winning. A section of each shaft is given to show the strata in the upper parts. The coal to be worked is the Barnsley thick coal at a depth of 730 yards. At a depth of 52 yards two pulsometers were raising 30,000 gallons hourly. Work was then suspended until pumps were obtained. As the ground was very loose, pumps of the suspended type were used. The Denaby chaser pump, which was employed, consists of three hollow plungers. The upper pair are stationary, and over them slide barrels which are connected to a steam piston. From the lower ends of these barrels the lower plunger projects and works in a fixed lower barrel. The fixed barrel and plungers are connected to the steam cylinder, and the movable parts to the piston. Delivery-valves are placed between the small barrels, and the large ram- and suction-valves at the bottom of the large barrel. The upper plungers are hollow; one is closed to serve as the air-vessel, the other forms the discharge. A telescopic suction-piece is used. The first pump made could lift 50,000 gallons per hour 300 feet high with 80 lbs. of steam. The pump was suspended by two old winding-ropes, and clamped in position. At 55 yards another similar pump, capable of lifting 70,000 gallons, had to be put in, but the sinking was stopped at 57 yards. The second pit was, however, being drained, so it was pushed on until it reached the same strata, when pumps were also put in. At 72 yards the first shaft was tubbed, before which the water lifted from the two shafts exceeded 400,000 gallons per hour. The second shaft was tubbed at 78 yards, and both shafts sunk to 100 yards. More pumps were then obtained, so that there were then eight at work, two in the bottom of each shaft delivering into a tank 70 yards from the surface. The sinking was then continued until the whole of the feeders were stopped by tubbing at about 131 and 123 yards. Eight Lancashire boilers, 30 by 7½ feet, were required for raising steam for all purposes.

Electric Pumping Plants.—The electric pumping-plant at the Jubilee Colliery, Shaw, has been running 100 to 150 hours per week since November 1891. The pump motor is 750 yards from the shaft, which is 120 yards deep, and the pump lifts the water to the shaft sump. An old engine is used and indicated, in a test made last January, 21·58 horse-power with the brushes off the dynamo, and 62 horse-power with them on. The "Oldham" series-wound dynamo gives 48·5 amperes at 580 volts, or 37·7 electrical horse-power. In the cables there is 1·05 horse-power lost, as their resistance is 0·33 ohm.

The motor is similar to the dynamo, and taking 48.5 amperes at 567 volts, runs at 406 revolutions, and gives out 35.53 horse-power. It drives the pump by rope-gearing. The pump delivered 577 gallons per minute against a vertical head of 142 feet, indicating 24.3 horse-power. The detailed results of the test as given show that the power used by the dynamo available at the motor is 86.1 per cent., the losses in dynamo cables and motor being 13.9 per cent.*

The electric pumping and winding plant at the mines of Faria in Brazil is described in considerable detail by A. Bovet.†

The electric pumping-plant which has been in successful use at the North Seaton Colliery for two months is illustrated.‡ The pumps are of the three-throw type, delivering 250 gallons per minute against a head of 50 feet. The rams are 9 inches in diameter and 15-inch stroke. They are driven through worm-gearing, running in oil, by a Tyne electromotor giving 20 horse-power at 720 revolutions. The current is supplied through 2700 yards of cable by a dynamo giving 65 amperes and 300 volts at 800 revolutions.

The electrically driven pumps at North Seaton Colliery are illustrated in *Engineering*.§ They are designed to deliver 250 gallons per minute through 1300 yards of 8-inch pipe against a head of 50 feet. The motor gives 20 horse-power at 720 revolutions, and is supplied through 2700 feet of cable from a dynamo giving 65 amperes at 300 volts.

Ventilating Appliances.—Mr. M. W. Brown|| gives a description of the Rateau fan, with the results of some experiments. This fan is made with thirty curved blades of a special form. Each vane has four edges, one of which is fixed upon the face of the wheel, the second forms the periphery, the third moves in close proximity to the casing, and the fourth edge is placed at the inlet. On leaving the fan, the air passes through a diffuser composed of three parts, first a flat spiral, then a square volute, and lastly a square expanding chimney. Experiments made with one of these fans, 6 feet 6½ inches in diameter, at the Aubin Colliery, showed efficiencies varying from

* *Electrician*, vol. xxix. pp. 695-696.

† *Mémoires de la Société des Ingénieurs Civils*; translated in *Engineering*, vol. liv. pp. 437-438, 443-449.

‡ *Industries*, vol. xiii. pp. 354-355.

§ Vol. liv. pp. 195 and 197.

|| *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 410-414.

56.3 per cent. at 290 revolutions, to 72 per cent. at 235 revolutions, and down to 46.8 at 184 revolutions.

M. Mortier* describes a form of fan devised by himself, and gives the results obtained by it. Essentially it consists of a wheel with curved vanes fixed on both sides of a central disc, and running in a circular casing pierced on the flat sides for the axle. Two rectangular ports are made in the cylindrical surface of the casing, the larger serving as the inlet and the smaller as outlet, and the centre of these passages are placed on a chord instead of on a diameter. This fan works without the intervention of centrifugal action, and the pressure at the circle of inlet is theoretically the same as at that of the outlet, so that the play is unimportant. A clearance of barely 2 inches will therefore suffice for a $4\frac{1}{2}$ foot fan. Experiments made with a fan of this diameter at La Peronnière gave an output of 565 to 1200 cubic feet, with a depression of 2.56 to 1.93 inches of water-gauge, showing an efficiency of 52 to 44 per cent.

The König differential water-gauge is described by Mr. M. W. Brown.† It consists of two concentric tubes one within the other, and both of them enlarged at the top to form two concentric chambers. One of these is placed in connection with the drift to be tested, and the other is open to the atmosphere. Two differently coloured and non-miscible liquids of nearly the same density are used in the two tubes, which are open to one another at the bottom, and a slight difference of pressure is evinced by a considerable motion of the heavier liquid in the central tube.

Safety-Lamps.—H. Gutmann,‡ referring to the recent terrible accident at Przibram, points out how extremely desirable it is that even in metal mines a closed lamp should be employed. He is of opinion that the lamp should have much the form of the ordinary safety-lamp; that it should burn benzene; that it should not weigh more than 28 oz.; and that by using a conical oil receptacle with a glass bottom, the shadow thrown could be reduced to a minimum. It must not be possible for the miner to open his lamp; and, if possible, there should be an arrangement attached for relighting the lamp without requiring it to be opened.

In a course of Cantor lectures on mine surveying, delivered before

* *Comptes Rendus Mensuels de la Société de l'Industrie Minière*, 1892, pp. 134-137.

† *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 432-454.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. p. 448.

the Society of Arts, Mr. Bennett H. Brough* pointed out that in fiery collieries where the dim light of a safety-lamp has to be used, the inconvenience of supplying the light for reading the verniers of a theodolite underground is especially great. Attempts have been made to increase the illuminating power of such lamps by the addition of lenses or reflectors† with more or less satisfactory results. An ingenious device recently suggested will probably come into general use. To two of the rods outside the glass cylinder of the safety-lamp a small plate is fastened by two screws. In the centre of this plate, opposite the flame, a tube is inserted, and into this a bored cork fits. Through the bored cork passes a curved glass rod, with a circular section 0·43 inch in diameter. The light which passes in at the terminal surface is totally reflected by the curved surfaces of the rod, and passes out at the lower end in full intensity. The free end of the rod, which can easily be moved in its cork holder, is placed over the vernier, and a steady adequate light is obtained. Even in mines free from gas it appears worth while to use a light safety-lamp for theodolite work, as the flame is so steady and so free from smoke.

J. Goffin‡ discusses at some length four methods of relighting safety-lamps without unlocking them. The first is that of Durant and Hubert, in which a platinum wire laid across the wick is carried by two insulated pins connected to contact pieces on the exterior of the lamp for making contact with any suitable source of electricity. In Mori and Rhodes' device the platinum wire is movable, and on depressing a stud which puts the wire in position, the contacts are exposed. Neither of these devices is self-contained, as the lamp has to be taken to a battery. In the Wolff benzine lamp, as used at Zwickau, a band of detonators is moved forwards by a plunger, and as each detonator is brought into position, it is struck by a trigger and fired. The author, however, prefers the Catrice relighter, in which a number of matches are carried by a revolving barrel, and are struck, as they are brought into position, by a roughened surface.

Miners' Electric Lamps.—The question of the construction and use of portable miners' electric lamps is discussed by Mr. S. F. Walker.§ In the first place a separate fire-damp detector is needed when these lamps are used, and it must be of such a form as to be as easily applied

* *Journal of the Society of Arts*, vol. xl, pp. 798, 809, 822.

† *Journal of the Iron and Steel Institute*, 1885, No. II., p. 580.

‡ *Revue Universelle des Mines*, vol. xviii, pp. 38-49, one plate.

§ *Colliery Guardian*, vol. lxi, p. 651.

as the cap on the flame of a safety-lamp. All the batteries, whether primary or secondary, give off acid vapours, and these, together with liquid leakage, soon damage the connections. The deterioration of the plates in secondary batteries from flaking, chemical change, and ill-usage is also a considerable drawback, especially as it is not easily detected nor remedied. The lamps at present sent out require for charging a current of one ampere for eight to ten hours, but a weaker current for a longer time is advisable. An amperemeter should be included in the circuit when charging. Lead plate, sulphuric acid cells give currents ranging from 2 volts downwards, and the charging current must have an electro-motive force of $10\frac{1}{2}$ to 12 volts. The cells may be charged from the electric light service by the interposition of suitable resistances. No primary battery has, as far as the author is aware, come into use at all in mines. The bichromate battery, which is the one that has mostly been tried, necessitates two liquids and a porous pot. Other solutions, many of them secret, have been tried. The connections in a primary battery lamp are more difficult than with the secondary cell, but in spite of these drawbacks the author is of opinion that the primary lamp has a greater chance of success since the operations of filling is preferable to charging by a dynamo.

New Fire-Damp Indicators.—A new form of alcohol lamp for the determination of firedamp has been devised by G. Chesneau,* with the object of overcoming some of the difficulties incident to the use of the Pieler lamp. Experiments were first made with lamps of the Marsaut and Wolff types, and these led to the adoption of a modification of the Fumat lamp. The air-supply enters at the base through a double gauze, which can be closed by a shield. A sheet-metal cylinder surrounds the wick tube and serves as a shade. The gauze is somewhat conical, and is surrounded by a shield pierced by a window for observation. It is found that the height of the cap and the flame depends considerably on the nature of the spirit used, so that alcohol of the same density should always be employed. The use of metallic salts to render the flames more distinct was experimented with, and it was found that the addition of cupric chloride was advantageous, giving a uniform green tint. This salt is soluble in alcohol, and is used to the extent of thirty drops of a concentrated solution in strong hydrochloric acid per litre. The height of the wick is adjusted by a regulating screw, and to insure, as far as possible, the

* *Annales des Mines*, 9th series, vol. ii. pp. 203-223.

same temperature, the lamp is allowed to burn about a quarter of an hour with the wick high. The tests should be made as quickly as possible, or else the lamp gets hot from the combustion of the gas, and the flame suffers an excess elongation. The author has found that variations of the carbonic anhydride and temperature of the air do not much affect the height of the cone when gas is present up to $2\frac{1}{2}$ per cent., although the luminosity is affected. Results of a number of experiments are given, with tabulated results of the height of the cone and of the luminosity for varying percentages of gas.

Murday's firedamp detector,* as adapted for colliery use, has been brought out recently, and is illustrated in the technical journals.†

Electricity in its Relation to Mining.—The applications of electricity to mining are dealt with by M. Saladin, ‡ who treats of the applications to getting, haulage, winding, and ventilation. The principal electric appliances used in French and other mines are described.

This subject is also dealt with by M. H. Fontaine, § who claims priority in the application of electricity for France. Before 1881 an electrically-driven fan was at work at the Blanzly Colliery, electric winches were in use at La Perronière, and Taverdon's rock drills were also in use. The question of sparking is referred to.

Mr. G. R. Rhodes || also deals with the general applications of electricity to mining, especially in America. In the United States far more use is made of water-power as the motive force than in this country. Abstracts from various American sources are given concerning coal-cutting and drilling machinery, haulage, and pumping.

Mr. G. Fletcher ¶ also deals with this subject, and gives some observations on electrical signalling and on the use of the telephone.

The subject is further discussed by Professor W. Robinson,** especially in relation to blasting and lighting.

The adaptation of the telephone at the Tankersley Colliery is described by Mr. W. H. Chambers.††

Electric Conductors for Mines.—A paper was read by Mr. R. J.

* *Journal of the Iron and Steel Institute*, 1892, No. I., p. 380.

† *Colliery Guardian*, vol. lxiv. p. 789; *Electrical Review*, vol. xxxi. p. 517.

‡ *Bulletin de la Société Internationale des Electriciens*, vol. viii. pp. 385-409.

§ *Bulletin de la Société d'Encouragement*; *Colliery Guardian*, vol. lxiv. p. 800.

|| Paper read before the National Association of Colliery Managers, November 28, 1891; *The Colliery Manager*, vol. vii. pp. 239-240.

¶ *The Colliery Manager*, vol. vii. pp. 246-247; vol. viii. pp. 29, 52-53.

** *Ibid.*, vol. viii. pp. 26-29.

†† *Ibid.*, vol. viii. p. 86.

Charleton * on a safety electric conductor for mines. This conductor has previously been described.†

Under certain circumstances the use of bare conductors may give rise to accumulations of explosive gas by electrolysis. If corrosion of the conductors also takes place, they may become heated and fire the gas. Such an occurrence, according to J. A. Montpellier,‡ took place in the conduits of the electric light mains in Paris.

The use of old wire ropes as conductors for electric light and power in mines is commented upon by Mr. S. F. Walker.§ Mr. Sopwith's plan of using old ropes has met with marked success at Cannock Chase, but there are considerable objections to their general use, especially in wet mines. If they are used they should be well protected by being pitched and wrapped with cloth, as any leakage that may arise is not objectionable on its own account alone, but also because of its possible danger. There is also much uncertainty as to their electrical resistance as the separate wires are broken, so that there is not a continuous path for the current, which accordingly has to overcome the resistance between the rusty joints and contacts. On this account the cable ought to be much heavier than six or seven times the weight of a copper conductor carrying the same current. The resistance of an old rope should be measured before it is put into service, and this may be done in several ways. One method is to stretch it out on the surface, supporting it on dry stones, and connecting it to the poles of a dynamo. The difference in the voltage between the poles of the dynamo and between one pole of the dynamo and the adjacent end of the ropes, divided by the current in amperes, gives the resistance.

The protection of electric light and power cables in mines is discussed by Mr. S. F. Walker,|| a short description of the principal methods in vogue being given. The use of iron-wire armouring is condemned, and preference is given to a simple covering of jute. This in itself is a good insulator and has considerable strength, while it does not impair the flexibility of the cable.

The Report of the Austrian Firedamp Commission.—The final report of the Austrian Firedamp Commission divides fiery mines into three classes containing less than 1 per cent., between 1 and 2 per cent., and over 2 per cent. of gas in the return air. A

* *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 570-573.

† *Journal of the Iron and Steel Institute*, 1892, No. I., pp. 354-355.

‡ *L'Electricien*, 1892, p. 253.

§ *Colliery Guardian*, vol. lxiv. p. 729.

|| *Ibid.*, pp. 826, 965.

number of recommendations relating to the size and position of the shafts and to the workings are given. The amount of ventilation is prescribed, the ascensional system being preferred, and the form of the fans is also dealt with. No special safety-lamp is recommended, but rules are given for their general use. Substitutes for blasting are generally inefficient, so that shot-firing is permitted under certain conditions, which are specified. The subject of coal-dust explosions is also treated with special reference to shot-firing in dusty mines. Soda-dynamite is recommended as a safe explosive. The general supervision and discipline are dealt with by special recommendations.

The experimental researches of the Commission are discussed by G. Chesneau * and the final report by René Grey.† Some remarks on the subject are also made by Mr. W. N. Atkinson.‡

Firedamp Explosions.—M. Raveaud § discusses the relations which exist between the disturbance of the air due to a firedamp explosion and the plan of the galleries in the mine. The first phase in an explosion is that of the combustion of the gas, and this gives rise to violent disturbances in the air throughout the rest of the mine where no gas occurred. These disturbances are often the cause of the greatest damage, as they destroy the passages and thereby interrupt the ventilation. As a general rule the air-wave will follow the straightest path it can, so that the effect in side-roads is often small unless something occurs or is present to deflect the disturbance. The author then proceeds to deal with the effect of variations in size and direction of the roads along which the air-wave is passing. Variation in size has not much effect, but that in direction has considerable result, as the speed and pressure of the current are convertible and some of the energy is converted into heat. If at any point the moving energy is converted into pressure by a change of direction, the disturbance may be propagated in all directions from that point as the pressure is reconverted, and thus at the shafts or elsewhere the results of the explosion may affect the different sections of the mine. To obviate this the author proposes two plans. The downcast is placed aside from the main intake air-road, which is put in direct communication

* *Annales des Mines*, 9th series, vol. i. pp. 239-264.

† *Bulletin de la Société de l'Industrie Minérale*, vol. vi. pp. 229-248.

‡ *Transactions of the Federated Institution of Mining Engineers*, vol. iii. pp. 531-534.

§ *Société de l'Industrie Minérale, Comptes Rendus Mensuels*, 1892, pp. 161-168, one plate.

either with the return air-way or with a third shaft, through which the explosion may take effect.

E. Homann* refers to the various recent experiments relating to the firedamp question, accounts of which have been published, and abstracts appeared from time to time in *The Journal of the Iron and Steel Institute*. The author considers, in the first place, these results in so far as they relate to the explosive character of coal-dust, and then passes to the question of the explosives employed, quoting largely from Mr. C. Cockson's paper. The results of the French and other commissions are also considered, as also are the observations which have been made as to the relative value of the various electric and other forms of lamps.

Since November 1891, according to L. Poussigue,† a very complete system has been in use at the Ronchamp collieries to determine the quantities of firedamp evolved. The aim has been to determine each day the exact amount present in all the return air-ways and working places, the nature of the gas enclosed in or liberated from the old workings, and from faults, fissures, &c. The colliery is in five divisions for ventilation purposes, and the amount of gas coming from each and at special points is determined. Samples are taken and analysed by combustion in a tube contracted at the upper end, according to the method indicated by H. Le Chatelier,‡ by mixing gas with the sample till it will explode. A very complete description of the apparatus and of the method of using it is given. For gas from the goaf, which often contains carbonic anhydride, a modification of Orsat and Coquillon's apparatus is in use. The results thus obtained have been compared with those given by the Pieler lamp, which often seems to give wrong indications, probably on account of the dampness of the air or similar causes. A table is given to show the volume of air passed, and of gas liberated, per ton of coal extracted. This quantity of gas ranged between 230 and 1585 cubic feet in February 1892, in the different districts.

The Barometer and Firedamp.—Dr. Runge§ publishes a number of observations on the relation between the height of the

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 329-334, 345-353, 383-387.

† *Bulletin de la Société de l'Industrie Minière*, vol. vi. pp. 249-282.

‡ *Journal of the Iron and Steel Institute*, 1891, No. II., p. 222.

§ *Zeitschrift für das Berg-, Hütten- und Salinenwesen im Preussischen Staate*, vol. xxxix. part 4.

barometer and the frequency of colliery explosions. The observations were made in the Ruhr basin. The annual mean height of the barometer during 1890 was 752·6 millimetres at Dortmund. The maximum was 768·45, and the minimum 723·10 millimetres. The monthly averages were as follows :—

1890.	Mean Height.	Above Annual Mean.	Below Annual Mean.	Number of Explosions.
January	753·1	0·5	...	12
February	759·4	6·8	...	7
March	750·0	...	2·6	9
April	747·8	...	4·8	6
May	748·9	...	3·7	5
June	753·3	0·7	...	6
July	750·8	...	1·8	9
August	750·5	...	2·1	4
September	758·2	5·6	...	5
October	754·6	2·0	...	15
November	750·1	...	2·5	5
December	754·6	2·0	...	8
Mean	752·6	...	...	...

The author considers that these results confirm, to a certain extent, the view that the danger of explosions in collieries is greatest when the barometer is low or falling.

Some Sources of Danger in Underground Working.—Some of the sources of danger in underground working are discussed by Mr. D. E. Davies.* The first of these is the goaf taking fire, and this generally occurs in South Wales from shot-firing. Some examples of this are given, and also of the danger of blasting in the main intakes, on account of the dust. Working a piece of coal in advance of the face gives rise to considerable trouble, on account of the gas and the difficulty of ventilation, and keeping the place open. Squeezing and gas are mentioned as some of the dangers in opening out a new seam, or beyond a fault. Walling-in gas, which used to be the general custom in South Wales, is strongly condemned, and the present system of causing a sufficient amount of air to pass through the goaves is to be preferred. It would also be advisable to do no winding in the upcast pit. The difficulties which occur in approaching water are also mentioned.

Lignite-Mining in Eastern Galicia.—J. Muck† observes that

* *Transactions of the South Wales Institute of Engineers*, vol. xvii. pp. 314-323.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 226-228.

outcrops of coal have been known for a lengthy period to exist in the neighbourhood of Kolomea, on the northern slopes of the Eastern Carpathians. In the year 1802 mining was in existence there, and in 1840 coal-mining was commenced in the Nowosielica district, but it was not until the year 1849 that in either of these districts was the mining for fuel effected on a scale of any magnitude. It is, however, only within the last two years that this industry has become of real importance. The lignite deposits exist in the Ispas sands of Neogene age, the roof being a clay slate. The main seam worked is about 18 inches in thickness. The lignite is of a deep black colour, contains 9 to 10 per cent. of ash, has a specific weight of 1.26, and a calorific power of 5200. The quantity of coal proved is estimated at about 13,500,000 tons. It is met with from the outcrop to depths varying down to 60 yards. Within the last two years the colliery at Myszyn has made considerable progress. The seam is worked on the pillar and stall system, and the daily output is now about 60 tons. The Nowosielica workings are now raising between 100 and 200 tons of the coal a day.

Mining in the Gard Coalfield.—The Mokta-el-Hadid Coal-Mining Company has undertaken considerable works in the basin of the Gard, in order to find coal at a depth exceeding 870 yards. To push on the work with rapidity, they put down a compressed air-plant in 1887. The installation is described by M. Nagel.* The air is compressed by a Dujardin compressor, which is cooled internally, and has cam-actuated valves. The cylinder is 21.27 inches in diameter, with a stroke of 27.56 inches, and is driven at 45 strokes per minute by a 23.62-inch cylinder. There are three air reservoirs with a capacity of 1060 cubic feet. The air-pipes are of iron 2.36 inches in diameter. Eclipse rock-drills, giving 400 blows per minute, are employed. They are carried by radial arms on a vertical column fixed by screws. The stone is removed by an incline up which it is hauled by a winch driven by compressed air. Details of the deepening of the pits at Gagnières to a depth of 880 yards are given, together with a section of the strata passed through.

Mining in the Ruhr Coalfield.—Luthgen† gives a critical

* *Comptes Rendus Mensuels de la Société de l'Industrie Minière*, 1892, pp. 81-90 with five plates.

† *Zeitschrift für das Berg-, Hütten- und Salinenwesen im Preussischen Staate*, vol. xl pp. 289-308, with two plates.

description of the methods of working in vogue in the Ruhr collieries. On the whole, he finds that methods in which packing is employed are more expensive to work than bord and pillar methods when sufficient waste material is not available on the spot. In some cases, however, it is impossible to work the seams by the bord and pillar method. The loss with longwall and other methods in which filling is used is always less than in the bord and pillar method. The ventilation, too, as is shown by the returns of the explosions in 1889 and 1890, is considerably better, and the accidents caused by falls of roof and sides are far less. With regard to the protection of the earth's surface, the methods in which filling is employed have not been sufficiently long in use in the Ruhr coalfield for conclusive evidence to be available as to the merits of such methods. It has, however, been found that where subsidence has occurred due to workings that have been filled in, it has only been observable in an unappreciable degree, and has been so gradual as not to injure buildings on the surface.

Coal-Mining in Saxony.—At the Kaiser Colliery, near Gersdorf,* a number of hand-drills of a rotary type are in use, and are capable of boring 39 inches in sandstone in a quarter of an hour. Roburite is used as the blasting agent. These hand-drills are also in use at other Saxon collieries. Sharon's pneumatic chisel has been tried with varying results. The Plom enlarging drill was tried at the Zauckerode collieries, but gave unsatisfactory results, the ground being very hard in places. Better results were obtained with this drill at the Zwickau collieries. The electric diamond drill has been used both for sinking and driving at the Zauckerode mines, but its use has been temporarily abandoned, as the Carboniferous clay sandstone which had to be dealt with caused a heavy loss of diamonds when compared with the work performed. This had, however, been anticipated. At the Hoffnungs shaft of the Lugau Colliery Company experiments were made with the explosive carbonite. This explosive was used in the coal, and the results were unsatisfactory. It showed a tendency to rapidly decompose. Trials of roburite which were made at Oelnitz only gave satisfaction when a dynamite cartridge was added to the roburite charge. In this case the results were even better than when dynamite was used by itself alone. Another new explosive, lithotrite, was also tried at another colliery. The results were not favourable. The use of the Lauer igniter having led to an accident,

* *Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen*, 1891, pp. 135-151. 1892.—ii.

experiments were made by allowing these rods with their charge to fall from varying heights on to an iron plate. Of twenty such rods one exploded when dropped from a height of about 7 feet, while none of the rest exploded when dropped from a height of over 11 feet. Of a new set of twenty only one exploded when dropped from a height of over 16 feet.

Coal-Mining in Canada.—An account is given by Mr. R. Robertson* of the coalfields of Cape Breton Island. The history of the field is first shortly given, and is followed by an account of the pits now at work. Near Sydney harbour there are two shafts 13 and 11 feet in diameter and 670 feet deep. The smaller is used for pumping and for ascent and descent. The larger is used for winding 1000 tons per day. The engine is of 160 nominal horse-power, and raises two tubs placed end to end in the cage. Each tub carries 14 cwt. A bed of spruce boughs at the bottom breaks the fall of the cage. Two hauling-engines at the pit bottom are supplied with steam from the surface. A main and tail-rope system of haulage is in use, and particulars are given of the inclines, &c. The coal is brought from the face by horses. A pillar and stall system of working is employed, but the pillars are not removed as the workings are under the ocean, and a detailed account of these workings is given. The ventilation and pumping are done by a Guibal fan and by a Cornish engine. Electric light and signals are installed.

Coal-Mining in China.—In a recent report to the Foreign Office, the consul at Hankow, Mr. C. T. Gardner,† describes two coal-mines, one at Tao-shi-fu, the other at Wang-san-shih. At the first named place there are only very thin seams, and only the surface coal, of poor quality, has been worked. Borings are, however, being put down. At the latter place there are three seams, measuring 24 feet, 3 feet, and 14 feet respectively, and dipping 50° to the south. A shaft has already been sunk to a depth of 104 feet. The place is only three miles from a railway which is being built, and six miles from the iron-mines. Unfortunately the coal will not coke. The machinery was brought to the mine up a small creek, by damming it as the rafts advanced, so as to get sufficient depth of water.

Mr. W. Moses‡ states that of thirteen seams of coal cut at the

* *Transactions of the Mining Institute of Scotland*, vol. xiv. pp. 43-48.

† *Foreign Office Reports, Miscellaneous Series*, No. 247.

‡ *Mining Journal*, vol. lxi. p. 1071.

Kaiping collieries six are workable, three being of good quality. The best is 5 feet 6 inches in thickness, yielding an excellent steam coal. The remaining seams vary from 12 to 30 feet in thickness. They lie at an angle of from 40° to 90° , and are very difficult to work, both the pillar and stall and longwall systems being in use. The workings are very extensive. The output from two shifts is 1400 tons a day. The surfacemen work ten hours a day. The rate of wages is but sixpence a day. Large coke and brick works are erected in connection with the collieries. Another colliery has recently been sunk about twenty miles from Tong Shan, and is now producing at the rate of 500 tons a day. A railway is constructed from the mines to Tientsin, a distance of a hundred miles.

IX.—COAL-WASHING.

Coal-Washing Machinery.—S. Stutz * describes, by the aid of five illustrations, a coal-jigging or washing machine. The machine, which is described in detail, is stated to be much stronger and more compact than those in general use, and to be especially adapted for jigging the smaller sizes of anthracite coal. The stroke of the piston varies from 2 inches downwards, and it makes from fifty to a hundred double strokes per minute.

Coal-Screening Plant.—The screening plant at the Lumphinnans Colliery, Fifeshire, is in two sections, dealing with round coal and with dross. The coal plant consists of a series of picking tables with fixed bar screens. The tubs are emptied by tipplers into a hopper, whence the coal is distributed by "Mungall" bands to fixed screens and then to the four picking tables, which vary in length from about 47 to 11 feet, all being 4 feet in width. The dross taken from the coal is passed to travelling belts, which delivers it to the dross pit. It is then lifted by an elevator to a revolving screen making five sizes. The smallest size is taken by screw conveyors to the boilers or waggons, the small or single nuts pass direct to the waggons, and the three larger sizes of nuts are sent over three picking tables. The whole plant is covered in and lighted by incandescent electric lamps.†

Mr. W. Bridget ‡ describes the movable screens of his own design

* *American Manufacturer*, vol. li. p. 190.

† *The Colliery Manager*, vol. viii. p. 196.

‡ *Transactions of the National Association of Colliery Managers*, vol. iv. pp. 108-116.

which have been in use for some years at the Fishley collieries, for loading canal boats direct from the tubs. The screen is a travelling one, so that the men in charge have a length of two boats, and can take the coal and deposit it on any part of the boats. The screens are moved in either direction by attaching them with ordinary rope clips to a rope running at $1\frac{1}{2}$ mile per hour. The same engine that drives this rope also drives a second endless rope, which moves the tubs. There are two screens at work capable of dealing with 700 tons of coal per eight hours. The ropes work under the screens and are placed 7 inches apart. A boat can be loaded in fifteen minutes. Each screen has a total area of 34 square feet, steel bars 9 feet long being employed. The screen may be moved by hand if power is not available.

Drawings are published* of a new coal-screening plant erected at the Graf Bismarck Colliery at Gelsenkirchen. The products obtained consist of mixed coal, lump coal, and two sizes of nut coal.

The Manufacture of Briquettes.—Some notes on compressing brown coals into briquettes are given by Mr. B. Straubel.† The principal point in the manufacture consists in the proper selection of the methods for drying and heating the coal before it is compressed. Unlike other coals, brown coal contains enough bituminous material, so that admixture with pitch or other binding material may be omitted; but as the constitution of coals from neighbouring districts varies greatly, very careful selection of the methods and machinery is requisite. The processes are considered under three heads:—

Crushing the raw and wet coal.

Drying and heating the crushed material.

The compression of the brown coal into briquettes.

Crushing is best performed between a pair of rolls—one plain, the other closely fluted. The crushed material is passed over an inclined sieve, or over two if the material is fibrous, as it is essential that large pieces be removed. The coarser material is re-crushed or is used under the boilers. The crushed coal is then taken by conveyors to the drying-stoves, where the water is reduced about 35 per cent. down to 15 per cent., which is found to be a suitable amount. As a rule, highly bituminous coal contains less water and requires a lower temperature to dry it. The ovens which have been adopted may be classified under five heads, namely, those drying by (a) fire-gases alone, (b) steam only,

* *Glückauf*, vol. xxviii. p. 701.

† *Annual Report for the Secretary of Mines, Victoria, 1891*, pp. 49-52, one plate.

(c) hot air only, (d) hot air and steam, (e) fire-gases and steam. Examples of each of these types of ovens are described and illustrated. A recent improvement is the use of a large re-heating chamber, in which the coal from all the ovens is collected and re-heated. Some coal indeed requires a second crushing and sifting before it is re-heated. The ratio of compression varies with the coal, but averages 45 to 50 per cent. The author concludes with an estimate of the expense of compressing brown coal in Victoria, the Gippsland coal being employed.

Coal Tippler.—Mr. L. Gundlach * describes a form of coal tippler designed by himself and used in New South Wales. The tippler is double acting, holding two tubs, and is connected with a water-tank somewhat of hour-glass form, which acts as a balance to control the turning, which is rendered automatic. A curved screen and shoot guide the coal in its fall.

The Transport of Coal.—Preparations are being made for the transport, by a current of water, of coal from the Connellsville district to New York. The coal will pass through the pipes at the rate of five miles an hour. After the water has been separated, the coal is to be converted into briquettes.†

Loading Coal.—The iron coal pier of the Norfolk and Western railroad at Norfolk, Virginia, is described by Mr. W. W. Coe.‡ The pier is 805 feet long, and is approached by a single line. On each side there are two delivery tracks, with a gradient of 9 inches in 100 feet, and a return track with a grade of $2\frac{1}{2}$ per 100. Shifting tables are used to transfer the trucks. The foundations are made with hollow piles, of which particulars are given.

* *Engineering*, vol. liv. p. 355; one illustration.

† *Iron Age*, vol. xlix. p. 723.

‡ *Transactions of the American Society of Civil Engineers*, vol. xxvii. pp. 125-128, with three plates.

PRODUCTION OF PIG IRON.

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I.—BLAST-FURNACE PRACTICE.

The Selection of Ores, Limestones, and Fuels for the Blast Furnace.—Some notes on the selection of iron ores, limestones, and fuels for the blast furnace are given by Mr. F. W. Gordon,* together with a series of rules, and illustrations of the calculations employed. The formulæ are based on the assumption that the heat requirements for a given mixture are measured by a constant required by the oxide of iron, added to that required for a unit of slag, multiplied by the weight of that slag per unit of iron. Sir Lowthian Bell's figure of 2854 calories is taken as the heat required for oxide of iron per unit of pig iron made. Dividing this by the heat evolved and utilised per unit of carbon gives the quantity of carbon, less that absorbed by the metal. The quantity of slag is also calculated from the materials used. This amount multiplied by 1050, its heat requirement per unit, and divided by the heat units of the carbon, gives the amount of carbon required to melt the slag. The sum of the amounts of carbon required to form the iron and the slag, together with that absorbed by the iron, gives the total carbon, whence the amount of fuel required is easily found. It is assumed that all oxides of iron require the same quantity of heat for their dissociation, and that the slag is kept constant and free from excessive sulphur. The temperature of the blast is taken at 1300° to 1500° F., but other temperatures may be substituted.

* *Transactions of the American Institute of Mining Engineers*, Baltimore meeting (advance proof).

The problems treated begin with the efficiency and weight of the limestone; the weight of the slag due to the impurities in the ore, flux, and fuel; the carbon per unit of iron; the available carbon of the fuel; the fuel required per unit of pig iron; and the manufacturing cost, which is divided so that each of the different materials, according to its purity, would bear its proper proportion. Finally, a calculation is given of the cost of the pig iron, based upon the purchase price of the materials, with the actual cost of manufacturing and the calculated cost of the materials. The problem is worked out at length with the aid of twenty-six rules and the corresponding calculations, and although a particular case has been taken, yet the factors can readily be varied as required.

American and European Blast-Furnace Practice.—In a lengthy comparison of American and European blast-furnace practice, based on the results published by Gayley and Potter, E. de Billy* points out that the favourable local conditions prevailing in America are not met with elsewhere. In Europe it would be difficult to obtain similar out-turns. It is, however, a moot point whether it would not be advisable to adopt American principles to a certain extent. On the Continent a prejudice exists against wide boshes and powerful blast, and it is possible that the run of the furnace might be improved by widening the boshes and increasing the blast.

The Americans have two excellent principles which might advantageously be followed. The run of the furnace is regulated by the number of revolutions of the blowing-engine. Each furnace must have its own blowing-engine. Independence of the furnace in blast and regulation by means of the engine revolution are the two essential principles of American practice. They have given excellent results, and deserve the attention of European ironmasters.

Some notes on the manufacture of iron are given by Mr. H. Webb.† After a description of the Catalan forge, the author turns to the blast furnace and gives a general statement and comparison of the practice in the various iron-producing districts, including Cleveland, Cumberland, Lancashire, Wales, Lincolnshire, and Scotland. American practice is also mentioned. Reference is made to the stoves, and then puddling and forging are discussed.

The Preservation of the Hearth and Bosh-Walls of the

* *Annales des Mines*, 9th series, vol. ii. pp. 67-117.

† Paper read before the Manchester Association of Engineers, February 27, 1892.

Blast Furnace.—The various methods employed for the preservation of the hearth and bosh-walls are reviewed by Mr. J. Gayley,* and a full description is given of some of the devices in use. Thin walls and water-coils inside the jacket have a considerable effect, but for making pig iron, cooling plates or boxes built into the brickwork afford equal protection against breaking out and are more efficient. One of the first of these devices known to the author was Hunt's cooling-plate in 1877. This had a single water-way, but others with snake-coils and with two water-passes were introduced. Bronze was also substituted for iron with economy, as in the case of the tuyeres. The inner pass of cast iron two-pass plates soon gets destroyed, and the furnace lines alter, so a demand arose for plates that could be renewed. Fronheiser's plate meets this demand, and uses low-pressure water, whilst Scott's plate uses high-pressure water. The top of Scott's plate is arched, and it is set in arched recesses in the walls, special bricks being required. A plate designed by the author has been in use at the Edgar-Thomson furnaces, and does not require special bricks. It is wedge-shaped and strengthened by internal studs, so that it can support the masonry and yet be withdrawn. At these furnaces they are placed up to 12 feet above the tuyeres, but they have been used higher with advantage.

The bricks are equally important as a factor in the preservation, but very little change can be made in the fireclay itself. It is by the preservation afforded by carbon that the bricks are able to stand, or they would at once be fluxed away by the slag. The brick material is replaced by carbonaceous matter to the depth of several inches, especially with a basic slag. The following analyses are of bricks thus altered taken from the boshes:—

	I.	II.	III.	IV.	V.
Carbon	46.62	28.15	28.79	35.75	35.71
Silica	17.50	22.05	26.57	24.70	20.90
Iron	5.12	2.01	16.40	4.78	4.50
Alumina	7.07	8.63	8.71	10.89	7.71
Magnesia	3.01	3.76	2.85	6.78	3.26
Lime	15.78	27.63	17.06	14.22	3.12
Calcium sulphide	2.35	2.89	3.76	2.85	—

Nos. I. and II. were from one furnace, III. and IV. from another, and No. V. from a furnace making ferro-manganese. The material in

* *Transactions of the American Institute of Mining Engineers*, Baltimore meeting (advance proof).

No. V. also contained barium oxide 1.01, sulphur 0.24, and manganese 17.70 per cent. The author was induced to use carbon bricks for a lining. The coke bricks used contained—

Carbon.	Silica.	Ferrous Oxide.	Alumina.	Lime.	Magnesia.
64.23	21.51	1.41	12.05	0.67	0.29

Carbon bricks have been used in Germany not only to line the crucible but also the boshes of the furnace, and the author concludes that these bricks will be used in addition to the cooling-plates.

In the discussion, Mr. E. C. Pechin gave some further information as to the cooling-plates, and Mr. Gayly gave the details of the Edgar-Thomson furnace I. Professor von Tunner mentioned the blast furnace at Donawitz, near Leoben. Here it was found that the carbon lining of the hearth and boshes stood well, until the furnace was run on white iron, when the bricks in the hearth disappeared, owing to absorption of the carbon by the metal. As, however, the carbon bricks were surrounded by magnesite, the furnace continued running.

The Refractory Masonry of Blast Furnaces.—No material is yet known which will thoroughly withstand the dissolving action of the charge of a blast furnace. For this purpose, coke bricks have been recommended. They have been used in the South of France as furnace-linings since 1876, and are suitable for the construction of the body of the furnace but not for that of the boshes and the hearth, inasmuch as carbon would be taken up from them by the iron. According to Lürmann,* the best method of preserving the walls of a blast furnace, irrespective of the refractory material employed, is cooling with water. The causes of the rapid wear of the masonry of blast furnaces are: (1) friction from the descent of the charge, which may be avoided by the employment of harder bricks; (2) action of the constituents of the blast-furnace gases, such as cyanogen; (3) action of salt, due to the presence of saline springs in coal-measures, and to the quenching of coke with saline mine water; and (4) disintegration caused by segregations of carbon from carbonic anhydride, brought about by iron existing as FeS_2 within the fire-bricks. Iron pyrites, when acted on by heat, is converted into iron sulphide, which is in its turn converted by the blast-furnace gases into metallic iron, and the globules of this becoming enveloped by carbon from dissociated

* *Thonindustrie Zeitung*, vol. xvi. No. 2.

carbonic anhydride, continue to increase in size until the fire-brick breaks. In conclusion, the author advocates the experiment of constructing the body of a blast furnace of carbon bricks, or of ingot iron cooled by water, and the boshes of firebrick.

V. Deshayes * discusses the refractory materials used in blast furnaces, referring to the publications on this subject of Gayley, Le Verrier, De Billy, and others. The author considers that, as a general conclusion, the best results are obtained with a blast furnace when using carbon bricks to line the crucible portion of the furnace; cooling energetically; thin walls; and bronze or copper tuyeres. A brass tuyere with divided bronze cooling arrangements is the most desirable form at present.

Manufacture of Pig Iron in Luxemburg and the Rhine Provinces.—The iron industry in Luxemburg and the Rhine provinces is dealt with at some length by G. Bresson.† The oolitic iron ores of the Meuse and Moselle are used in the four following districts: (1.) In the French works of Meurthe-et-Moselle, the production was 1,078,632 tons, or more than half that of France. (2.) The works of Alsace-Lorraine, together with the Saar works, constitute the second district. (3.) The Luxemburg district is placed in the midst of the most favourable development of the ore deposits, and draws its coke from Belgium and Germany. At present the works mostly consist of blast furnaces, but steelworks and rolling-mills are being erected. (4.) The works of the Ruhr basin are situated in the coalfield, so that their ore has to be imported, but the iron and steel works of this district have always taken first rank in Germany. It was in this last district that the basic process was first adopted on the Continent.

The raw material mostly used is the oolitic iron ore, the output being more than half the total production of the whole of Germany, and, including the French district, more than nine million tons of ore were raised in 1890. Owing to the low iron contents of the ore, it is costly for transport, but efforts have been made to increase the use of water-carriage by canalising the Moselle, though this is opposed in the Lahn and Sieg valleys. The Ruhr cokes are strong and contain but little ash, though they are more sulphurous than the cokes of northern France. The recovery of by-products in this district is attracting attention.

In discussing the dimensions of the blast furnaces, the author points

* *Génie Civil*, vol. xxi. pp. 147-151, with illustrations.

† *Annales des Mines*, 9th series, vol. ii. pp. 5-20.

out that in Luxemburg there are installations which, though not comparable to those of the Edgar-Thomson Works as regards outturn, present on comparison several points of interest. This is shown by the following figures:—

Description.	America.	Luxemburg.
Height	88 feet 7 inches	65 feet 7½ inches
Diameter { at boshes	21 feet 9 inches	24 feet 9 inches
{ at throat	15 feet 3 inches	13 feet 6 inches
{ at crucible	11 feet 0 inches	10 feet 0 inches
Capacity	19,070 cubic feet	17,658 cubic feet
Volume of blast	25,781 cubic feet	17,658 cubic feet
Temperature of blast	625° C.	850° C.
Pressure of blast	1·85 inch	0·71 inch
Number of tuyeres	7	6
Yield of charge	62 per cent.	34 per cent.
Consumption of coke per ton of iron	1851 lbs.	2314 lbs.
Production per twenty-four hours	350 tons	100 tons

In the Luxemburg blast furnaces, the temperature rather than the volume of the blast is sought to be increased, and Cowper stoves are generally preferred. A furnace, such as that described above, generally has four stoves about 65 feet high and 19½ feet in diameter. Large blowing-engines running at low speeds are in general use, but several types have been employed, and the practice in these points is compared by the author with that adopted in America, the dimensions of some of the engines being given. To preserve the shape of the lining, cooling-plates built into the walls, especially of the boshes, are coming into general use, and in the most recent furnaces the hearth has also been protected in a similar manner. Open-topped furnaces are still at work, and are strongly upheld by some ironmasters, who claim that they can draw off as much gas from them as from the closed furnaces. Both in France and in Germany the direct metal process and remelting in cupolas before charging into the converter are in use. At the Rothe-Erde Works the cupolas are 23 feet high and 10 feet in diameter, whilst at Hörde the liquid metal from the blast furnaces is stored in a receptacle holding nearly 100 tons. As the Luxemburg and Lorraine ores by themselves only yield metal containing about 2 per cent. of phosphorus, puddle cinder, which at present is easily obtained, is added to the charge. Sulphur, on the other hand, is kept out of the metal as far as possible by the use of manganiferous ores. As these are becoming scarce in the district, recourse is being had to foreign ores.

New Austrian Blast Furnace.—At the Donawitz Works of the Austrian Alpine Mining Company a new blast furnace has recently been erected. It has an internal capacity of 12,996 cubic feet, and produces daily about 150 tons of pig iron. It is provided with three Whitwell stoves, a hydraulic attachment for the cup and cone, and a blowing-engine capable of affording 17,658 cubic feet of blast per minute. The works is lit by electric light.*

The Londonderry Blast Furnace, Nova Scotia.—According to Mr. R. G. Leckie,† the blast furnace at the Londonderry Ironworks was rebuilt in 1890, and blown-in in April of that year. It is of the ordinary type, having a height of 75 feet, width at boshes 18 feet, diameter of hearth 9 feet, diameter at stock line 14 feet, and diameter of bell 10 feet 6 inches. It is blown with seven tuyeres, each $4\frac{1}{2}$ inches in diameter. The gas down-take is 4 feet 6 inches in diameter, and the dust-catcher is a circular iron chamber 25 feet high and 10 feet in diameter. Inside it has two diaphragms, between which the gas passes downwards and then rises up behind them to a gas conductor, which on one side leads to the boilers and kilns, and on the other side to the hot-blast stoves. The gas in its passage through the dust-catcher deposits a large amount of dust, and this fact enables the stoves to be run for nine months without cleaning, instead of for three months, as was the case before its introduction. The bell of the furnace is of novel construction. Instead of being a plain cone, the periphery is indented, a space 8 inches wide alternating with a plate 12 inches wide, so that a more regular distribution of the fine and coarse ore is effected. Although the bell is 2 feet larger in diameter than the hopper, it was put in without removing the latter. The bell was cast in two pieces, a section being cut off by an interposed slip. After the main portion had been swung into place, the cut-out portion was replaced and the two bolted together by raised flanges on the upper side. Since the introduction of this bell, the hanging and slipping which had previously caused irregularity in working ceased. The tuyeres, too, which had been frequently destroyed, now give little trouble.

The removal of slag is an important item in cost, and the experiment now in operation appears to answer well. It is simply an adaptation of the tail-rope system to the slag truck. Further improvements are in contemplation which will render the discharge of slag automatic, and so reduce the handling to a minimum.

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xi. p. 515.

† *Canadian Mining Review*, vol. xi. p. 155.

Blowing-in of a Blast Furnace.—Some notes on the blowing-in of No. 1 furnace at Ensley, Alabama, on a new lining, are given by Mr. J. S. Kennedy.* The furnace was originally 80 feet high, and had boshes 20 feet and hearth 11 feet in diameter, with the boshes 37 feet above the hearth. This was lowered to 28 feet by reducing the diameter to 19 feet, as the bosh angles could not be altered. The furnace was well dried by a month's hard firing, so that the temperature first given by the stoves was 800°. It was thus possible to rapidly increase the amount of blast without lowering the temperature. The hearth was filled with an extra amount of wood as only pine was available, and a fuel blank of 20,000 lbs. of coke was charged. Then 78,000 lbs. of coke with 12 per cent. of limestone was put in, and followed by a mixture of hard and soft ores with flux. The first seven charges were: coke, 6500 lbs.; ore, 4000 lbs.; limestone, 980 lbs. The burden was raised every seven charges till 6500 lbs. coke, 8700 lbs. ore, and 2000 lbs. of limestone were charged. Greasy waste was placed in front of the tuyeres and lighted, and 7000 cubic feet of blast at 820° was blown in. This was increased to 16,000 feet in twenty-four hours. The first slag was tapped fourteen hours after lighting; it was hot, grey, and fluid, and contained 35.41 per cent. of silica. The first cast of 17½ tons was made two hours later, and on the sixth day 155 tons was made, of which 108 tons was foundry iron. The furnace then carried 6500 lbs. of coke, 2700 lbs. of limestone, and 11,680 lbs. of ore.

Smelting the Titaniferous Iron Ores of the United States.—Dr. R. W. Raymond† calls attention to the persistent appearances of the titaniferous ore belt mentioned by Mr. H. B. C. Nitze‡ among the iron ore deposits of North Carolina, and thinks that it is a fairly definite geological horizon which may be of use in determining the age of other ore belts. The Church ore of New Jersey contains as much as 15 per cent. of titanite anhydride in some specimens, and vanadic anhydride also occurs, but could not be successfully concentrated. Titaniferous ores are only used with difficulty in the blast furnace, but the quality of the iron produced is good, because the iron is free from phosphorus and is made at high temperatures with a difficultly fusible slag. These ores have occasionally been used to check the cutting out of hearth

* *Proceedings of the Alabama Industrial and Scientific Society*, vol. i. part 2.

† *Transactions of the American Institute of Mining Engineers*, Baltimore meeting (advance proof).

‡ *Journal of the Iron and Steel Institute*, 1892, No. 1, pp. 278-280.

walls. English practice in the use of these ores with a highly aluminous slag is referred to. Mr. Birkinbine, supported by Mr. H. M. Howe, suggests the use of a removable hearth for the furnace to obviate the difficulties from the building up, and the possibility of the diminution of the titanium by magnetic concentration is being investigated by Professor T. Eggleston.

American Charcoal Blast Furnaces.—Mr. J. M. Hartman* states that the blast furnaces erected at Grand Rivers, Kentucky, form an extremely well designed and constructed charcoal plant. It consists of two 150-ton furnaces, each 60 feet high, 13 feet 6 inches in diameter at the boshes, and 7 feet 3 inches at the hearth. There are in each furnace six tuyeres placed at a height of 5 feet 6 inches above the hearth. The blast is supplied by vertical engines, having each a maximum capacity of 11,500 cubic feet of air per minute, at a pressure of 15 lbs. per square inch. Either or both of the engines may be attached to one or other of the two furnaces. The boilers number sixteen; they are of the 2-flue type, and possess a total available heating surface of 5624 square feet, and, allowing 30 square feet of heating surface for each ton of charcoal pig iron made in twenty-four hours, the boiler capacity is consequently equal to an output of 186 tons of iron in twenty-four hours. The blast is heated by two double batteries of pipe stoves of the Durham type. The stock-house is 408 feet in length, and 72 feet wide; two lines of rails laid on trestles 16 feet above the floor line run the entire length of the building. The casting-houses are of wrought iron throughout, and cover a space of 131 by 50 feet, with parts 24 feet in height. The furnaces are erected on the banks of the Tennessee River, and there are thus great facilities for the transport of the product, and for obtaining the necessary ore, fuel, and flux, without being in any way dependent on railway communication.

New American Blast Furnace.—The North Carolina Steel and Iron Company has erected at Greensboro a new blast furnace equipped with stoves of the Ford and Moncur type. Its dimensions are 70 by 14 feet, and working on local magnetite ores and haematite, with Pocahontas coke, the estimated annual capacity of the furnace is 30,000 tons.†

A description, accompanied by a plan and illustration, of the plant

* *Iron Age*, vol. I. pp. 322-324, five illustrations.

† *Ibid.*, vol. xlix. p. 307.

of the Monongahela Furnace Company, M'Keesport, Pennsylvania, is given.*

New Hot-Blast Stoves.—Messrs. M'Clure and Amsler † of Pittsburgh have designed a hot-blast stove which is a modification of the Massicks and Crooke's stove, and a number of this modified form of stove have been erected in the United States. The main object aimed at is to effect at the top of the stove a connection between the vertical flues and the stack flue, so constructed as to obviate the liability to fracture of the walls by expansion and contraction. This is effected by making the connecting passage in the form of an arch made separate from the crown of the stove, so that there is an intervening space instead of flues in the crown itself.

In this pipe stove there is no combustion chamber beneath, but there is a small one at the end where the gas enters, is ignited, and passes into the oven through slots in the partition wall. There are thirty pipes in each section of the ovens as erected at the Grand River blast furnaces, Kentucky, each pipe having 65 square feet of heating surface. At Durham, where these pipe stoves have been in use since 1876, it has been found that 100 pipes, or 6500 feet of heating surface, will heat 16,000 cubic feet of air per minute, and that with regular running a temperature of 1000° F. can be maintained. At the Grand River, the double stoves, each with 3900 square feet of heating surface, maintained the above-mentioned temperature without difficulty during a run of ninety days, 8300 cubic feet of air being blown per minute.‡

Removing Skulls from Direct Metal Ladles.—Mr. D. Baker § describes the means in use by the Maryland Steel Company for removing skulls from the direct metal ladles. These ladles have a capacity of 18 tons when filled to within a foot of the top, so that the skulls, when they do form, are large. The chilled ring of metal at the top is kept chipped off, so that the skull principally forms at the bottom. The extractor consists of a horizontal, telescopic hydraulic ram, supplied with water at 750 lbs. pressure, the diameter of the rams being 14 and 8½ inches. The object of the small ram is to complete the ejection of the skull after it is started by the larger, and to save water. The hydraulic cylinder is mounted in a vertical plate, at each corner

* *Engineering*, vol. liv. pp. 140, 149, 150.

† *Iron Age*, vol. xlix. p. 864, three illustrations.

‡ *Ibid.*, vol. l. p. 323.

§ *Transactions of the American Institute of Mining Engineers*, Baltimore meeting (advance proof).

of which chains are attached by eye-bolts. Eyes on the other ends of the chains take over lugs on the ladle trunnion ring, and hold the ladle with its base towards the ram. In the bottom of the ladle and opposite the ram is a hole 18 inches in diameter. This hole is covered by a plate 2 feet in diameter, and the lining is put in so as to leave a circular hole 26 inches in diameter over this plate, which is afterwards covered with ganister and fire-brick. This is the only part of the lining which is destroyed when the skull is ejected, unless the lining is much worn when the sides come away. A coating of crude graphite is used to prevent the skull sticking.

The Collection of Ammonia from Blast-Furnace Gases.—In the twenty-eighth Annual Report of the Chief Inspector of Alkali Works of the United Kingdom, the amount of ammonium sulphate produced in the United Kingdom is stated to have been as follows:—

Source.	1891.	1890.	1889.
	Tons.	Tons.	Tons.
Gasworks	107,950	102,138	100,711
Ironworks	6,290	5,064	6,145
Shaleworks	26,600	24,730	23,953
Coke and carbonising works .	2,766	2,325	2,795
Totals	143,606	134,257	133,604

The author of the report observes that so valuable has the collection of the ammonium sulphate now become, that in some cases in an iron-works it is actually the iron which is the by-product, the ammonia being the main source of profit. Out of seventy-seven active blast furnaces in Scotland at the time to which the report refers, fifty-seven were provided with a condenser-plant for the collection of the tar, ammonia, &c., from the blast-furnace gases, the total outlay on this plant having been as much as £444,600. In England only three blast furnaces had such a plant attached to them, the cost of the plant being in this case £12,000 per furnace.

The Influence of Situation upon the Pig-Iron Industry.—This subject is discussed at some length by Mr. J. Birkinbine,* chiefly from the view of historical facts which have led to the position chosen for

* *Transactions of the American Institute of Mining Engineers, Presidential address, Lake Champlain meeting, June 1892.*

ironworks in the past. A certain amount of statistical information is, however, given for recent periods to show the production in different parts of the United States, and the proportion of the various ores, especially of Bessemer ores, is set out in a graphic form. In early periods the existence of easily smelted brown ores and of an abundant charcoal supply were the main factors in the erection of works, as the cost so much depended on these items. These potent factors were then counterbalanced by the extension of railways and by the concurrent introduction of hot-blast and steam-power. For the purposes of comparison four districts are taken. These are Eastern Pennsylvania, Pittsburgh, Chicago, and Birmingham in Alabama. A *resumé* of the industry, with several tables to illustrate the progress in these districts, is given. Some of the causes which have influenced, and which will further affect the industry, are thus presented by the author. The bearing of the ore and fuel supplies, the growth of the population, and the market offered by other localities which may also be competitors have all to be considered, both in producing and possibly productive districts. Under good management the maximum differences in the cost of production in these four districts for the same grade of pig iron is about 12s. per ton, but cheapening of transport brings on keen competition. The data presented indicate that, notwithstanding great developments in the steel industry, the proportions of Bessemer pig iron to the total industry have changed but slightly in five years, and that less than one-half of the present output is of Bessemer grade. The indications are that in the future successful iron industries will follow the population rather than form centres for communities in remote districts; that the tendency is rather to centralise the production of pig iron in large plants than to encourage the erection of individual furnaces except as initial developments of new industries; and that, while the manufacture of all kinds of steel will advance, there will be a large demand for iron made from ores not within the Bessemer limit for the production of foundry and other pig irons.

The Cost of Production of Anthracite Pig Iron.—Comparative statements are published showing the cost of production of anthracite pig iron at a blast furnace in the Lehigh Valley, Pennsylvania, in June 1857, and at the same furnace in May 1892. The detailed cost is as follows:—

	1887.	1892.
	Dollars.	Dollars.
Cost of coal per ton of iron	6.49	3.33
Cost of ore	8.46	5.78
Cost of limestone	0.49	0.35
Salaries and wages	2.76	1.65
Other items	1.34	
Totals	19.54	11.11

The year 1857 was the year of the great panic, and the cost was therefore low.*

Nickel-Iron Alloys.—The following method has been devised by Garnier † for the manufacture of alloys of iron and nickel :—The nickel ore is run down in a blast furnace for nickel regulus, which is then submitted to the action of a hot oxidising blast in a basic or neutral lined furnace. The result is stated to be an alloy of iron and nickel, or, if the oxidation is more rapid, metallic nickel.

II.—CHEMICAL COMPOSITION OF PIG IRON.

The Control of Silicon in Pig Iron.—In the discussion of a paper by Mr. W. H. Morris ‡ on the control of silicon in pig iron, Mr. B. F. Fackenthal § gives analyses of the ore, fuel, and limestone used at the Durham furnace, and of the slag and iron produced. He ascribes the presence of silicon in the metal chiefly to the character and composition of the ores used. With magnetic ores the silicon is low, but is raised by substituting half the weight of brown hæmatite ores containing silica in combination with the iron. Mr. F. E. Bachmann, however, using these ores, only gets low silicon, and he thinks that the silica should be free. Mr. G. F. Knapp gives his experience in the production of a low silicon and sulphur iron during several weeks. In his opinion the method of running the furnace, the temperature,

* *Iron Age*, vol. xlix, p. 1036.

† *Chemiker Zeitung*, vol. xvi, p. 571.

‡ *Journal of the Iron and Steel Institute*, 1892, No. I., pp. 403-404.

§ *Transactions of the American Institute of Mining Engineers*, Baltimore meeting. (advance proof).

and the basicity of the slag, are the controlling elements. Mr. Fackenthal again advances his views, and is to a certain extent supported by Dr. R. W. Raymond, and the question of grading is brought into the discussion. Dr. Raymond mentions the use of additions of ferro-silicon to make foundry irons from lower grades, and a method of reducing the silicon by pouring the metal through a column of fragments of basic slag.

The Grading of Pig Iron.—In some notes on the blast furnace, after dealing shortly with its history, Mr. J. M. Hartmann * gives the following typical analyses of the various grades of pig iron, with their characteristics, and illustrations of their fractures :—

Grade.	1.	2.	3.	4.		5.
Iron	92.37	92.31	94.66	94.48	94.08	94.68
Graphitic carbon	3.52	2.99	2.50	2.02	2.02	...
Combined carbon	0.13	0.37	1.52	1.98	1.43	3.83
Silicon	2.44	2.52	0.72	0.56	0.92	0.41
Phosphorus	1.25	1.08	0.26	0.19	0.04	0.04
Sulphur	0.02	0.02	trace	0.08	0.04	0.02
Manganese	0.28	0.72	0.34	0.67	2.02	0.98

No. 1. Grey. A large dark open grain iron, softest of all the numbers, and used exclusively in the foundry. Tensile strength and elastic limit low. Fracture, rough. Turns soft and tough.

No. 2. A mixed large and small dark grain, harder than No. 1 iron, and used exclusively in the foundry. Tensile strength and elastic limit higher than No. 1. Fracture, less rough than No. 1. Turns harder, less tough and more brittle than No. 1.

No. 3. Grey. Small grey close grain, harder than No. 2 iron, used either in the rolling-mill or in the foundry. Tensile strength and elastic limit higher than No. 2. Turns harder, less tough and more brittle than No. 2.

No. 4. White background, dotted closely with small black spots of graphitic carbon, little or no grain. Used exclusively in the rolling-mill. Tensile strength and elastic limit lower than No. 3. Turns with difficulty, less tough and more brittle than No. 3.

No. 5. White. Smooth white fracture, no grain, used exclusively in the rolling-mill. Tensile strength and elastic limit much lower than No. 4. Too hard to turn, and more brittle than No. 4.

Besides these there are many special grades and qualities of iron used for particular purposes.

The Removal of Sulphur from Iron.—In reference to Mr. Stead's summary of the processes for eliminating sulphur from iron, Mr. F. J. R. Carulla † gives the following analyses of steel made by the

* *Journal of the Franklin Institute*, vol. cxxxiv. pp. 132-144.

† *Industries*, vol. xiii. p. 368.

Heaton process, and also an analysis of the Stanton pig iron used for the metal C. :—

	Steel A.	Steel B.	Metal C.	Pig Iron.
Combined carbon	1·10	0·56	trace	0·41
Graphitic carbon	0·40	trace	none	1·70
Silicon	trace	none	none	2·05
Phosphorus	0·24	0·05	0·10	0·35
Sulphur	0·12	0·10	0·11	0·24
Manganese	0·47	0·50	0·72	1·92

Steel A. crumbled under the hammer at all heats, B. was worked into a bar with fine grain, and C. was worked into rails.

The Smelting of Gellivara Iron Ores.—According to the *Wermändska Annaler*, poor phosphoric iron ores, or rather ferriferous apatite, from Gellivara, in North Sweden, with 20 to 25 per cent of iron, have been experimentally smelted at Finshytte. The pig iron produced contained—

	Silicon.	Carbon.	Phosphorus.	Sulphur.
I.	0·08	0·50	10·64	0·03
II.	0·01	0·65	11·86	0·02
III.	0·15	0·59	13·11	0·01
IV.	0·15	0·79	9·78	0·06
V.	0·01	0·50	10·31	0·07

The corresponding slags contained:—

Description.	I.	V.
Silica	26·20-22·56	42·90-39·26
Alumina	4·59-4·44	7·98-7·39
Ferrous oxide	1·40-1·92	2·46-2·00
Manganous oxide	0·29-0·24	0·62-0·46
Lime	43·80-46·79	27·00-33·24
Magnesia	5·16-4·38	11·61-7·27
Phosphoric anhydride	15·48-19·67	5·71-10·23
Titanic anhydride	2·30	1·00
Sulphur	0·16	0·08

The charges consisted of—(i.) ores without any flux ; (ii.) with 10 per cent. of lime ; (iii.) with 15 per cent. of lime ; (iv.) 90 parts of ore with 20 parts of blast-furnace slag ; and (v.) 90 parts of ore and 10 parts of sand. Thus, in order to obtain slag richest in phosphorus, the ores must be smelted alone, or with a small addition of lime. The pig iron

should readily be purified by an oxidising smelting on the basic open hearth, with the addition of lime, if it is required to produce wrought iron or steel together with basic slag.

American Forge Pig Iron.—The following is an analysis of the special grade "Chickies" forge pig iron, made at Chickies, Pennsylvania, from ores mined in that district:—

Phosphorus.	Sulphur.	Silicon.	Manganese.
0.184	0.027	0.640	0.201

It is used in admixture with high phosphorus and cinder irons, and with high silicon metal from the Southern States.*

Titanium in Iron.—Mr. J. B. Nau† observes that titanium is frequently found in iron ores, and occasionally in large quantities. Thus a magnetite from Ulfö, in the Archipelago of Augermanland, contains 9.5 per cent. of titanic anhydride. Titanium is difficult to reduce, and by far the largest part of it passes into the slag in the blast-furnace treatment of the ore, giving it a dark and sometimes a perfectly black colour, traces being usually hard to find in the pig iron made, even when the slag contains 8 per cent. or more of titanic anhydride. Many experiments, made with a view to produce a titanium iron alloy in the crucible, have been unsuccessful; but Sefström, after he had heated in a graphite crucible first a mixture of iron oxide and titanic anhydride, and then a similar mixture with an addition of bisilicate of lime, succeeded in producing in the first instance an alloy with 2.2 per cent. of titanium, and in the latter an iron containing as much as 4.78 per cent. of titanium. The former was a velvet dark soft iron, while the other, with more titanium, was a very hard, though forgeable iron. In a third test an unforgeable, hard, white pig iron was obtained, which contained 0.5 per cent. of titanium.

Riley has shown that in the manufacture from a mixture of ore containing some titaniferous iron ore, pig iron is occasionally produced which contains 0.5 to 1.6 per cent. of titanium. In the blast furnace, too, crystals are met with having the composition $\text{TiC}_2\text{N}_3 + 3\text{Fe}_3\text{N}_2$. Titaniferous ores are hard to smelt, but it has been thought that the presence of such ores is favourable to the formation of a spiegeleisen, though the metal obtained contained only 0.15 to 0.2 per cent. of manganese. The author proceeds to discuss the extreme difficulty which is observed in the efforts to produce a titanium iron alloy, and

* *Iron Age*, vol. xlix. p. 781.

† *Ibid.*, pp. 550-551.

the probable great and beneficial influence exerted by even a very small quantity of titanium on iron. Iron obtained from titaniferous ores is, he adds, almost always of superior quality.

Calcium and Magnesium in Pig Iron.—A. Kaysser * gives the following partial analyses of pig iron made at the Altos Hornos Works at Bilbao, showing the presence of appreciable quantities of calcium and magnesium. As showing the influence exerted by these elements on the acid lining of a Bessemer converter, the number of blows is also given which a converter bottom withstood when the metal referred to was being blown :—

	Si.	Mn.	Ca.	Mg.	Number of Blows.
1	3.36	1.06	0.21	0.07	...
2	1.76	1.02	0.26	0.07	10
3	2.00	1.02	0.07	0.05	17
4	2.03	1.21	0.09	...	15
5	2.43	...	0.15	0.12	14
6	1.96	1.06	0.27	0.03	13
7	1.87	0.97	0.29	0.38	12

III.—BLAST-FURNACE SLAGS.

The Calculation of Slags.—The calculation of slags may, according to Mr. N. M. Langdon,† be considered under three heads. These are :—(a.) When a certain percentage of silica is required and the other slag-making elements will not hinder the formation of fusible slags with that amount of silica; (b.) when the slag is to conform to a general type with a certain oxygen ratio of bases to acids; (c.) when the slag is to conform to a specific type with a certain oxygen ratio of protoxide and sesquioxide bases as well as of total bases to acid, or to contain certain percentages of the different acids and bases. The first and second of these cases are usually limited to iron smelting, whilst cupola smelting may be considered under the third.

To find the percentage of flux to produce a slag having a given percentage of silica, a table of constants showing the percentage of bases present for each 1 per cent. of silica is given. These constants are

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. p. 256.

† *Transactions of the American Institute of Mining Engineers*, Lake Champlain meeting (advance proof).

multiplied separately by the silica in the ore, flux, and fuel, the bases are deducted from the products, and the remainder indicates the limestone required. For the second case, a table of the typical composition of nine different slags with the oxygen ratios and the character of the iron produced is given, and also a table to show the amount of silica required per unit of base to produce a normal silicate. Rules are appended for finding the percentage of limestone to produce a slag with a given oxygen ratio of bases to acid, for determining the general type of a given slag, for resolving a slag given by its formula into the percentage of its elements, and for determining the specific formula of a slag, an analysis of which is given. For the third case the method is described of finding from the analyses of the different ores, fluxes, and fuels, a mixture that will produce a given specific slag. Each of these rules is illustrated by a fully worked-out example.

Slag Cement.—According to Pinkenberg,* there are at the present time some ten manufactories in Germany where slag cement is made, the aggregate annual production being 600,000 tons. For the Berlin market, the slag cement is derived chiefly from the Victoria Works at Thale in the Harz, where slag sand from the Blankenburg and Harzburg blast furnaces is employed. The cost of production is 5s. per ton.

In the employment of slag cement for structural purposes, attention must be paid to two of its properties, which, under certain conditions, are disadvantageous. These are (1) the very slow setting (15 to 22 hours), and (2) the low specific gravity of slag cement.

The employment of slag cement under water in the construction of the Kaiser Wilhelm Bridge and of the Moltke Bridge at Berlin, has proved unsuccessful; on the other hand, slag cement has answered very well in ordinary building construction.

IV.—FOUNDRY PRACTICE.

Stove Foundry Practice.—There is considerable scope for economy of fuel in the melting of iron in the cupola, but the saving of fuel is often more than counterbalanced by the inferior quality of the product. The cupolas mostly used in stove plate foundries have an outside diameter of 5 to 6 feet, and a height of from 45 to 60 feet. A specification

* *Dingler's Polytechnisches Journal*, vol. cclxxxiv. p. 237.

which has been given * requires the lower two sheets of the casing to be $\frac{3}{8}$ -inch, and above that $\frac{1}{4}$ -inch in thickness. The sheets are riveted and the casing is strengthened by flanges. One or two charging openings are made 12 to 15 feet above the floor. They are $3\frac{1}{2}$ feet across and $2\frac{1}{2}$ to 3 feet high. Charging-doors lined with brick may be used. The tuyere openings should be 10 to 15 per cent. of the cross section of the cupola. Proper tuyeres and a tight wind-box should be used. The bottom plate should be heavy, and the cupola should rest on iron columns high enough to let the discharging-doors swing freely and to let the material be removed. The scaffold must be strong enough to bear the stock which it is intended to store there. The brick lining is laid in a grout of fine clay and sand, with salt added. A thinner lining may be used above the doors, as the greatest repairs are required at the melting zone, which may have to be relined three times yearly. The sand bottom over the doors is 5 to 7 inches in thickness, and is evenly sloped towards the tap-hole, and the breast is carefully made. Shavings, wood, and then a bed of coal are put in to light up, and charging can commence about an hour afterwards. The cupola may then be filled and the blast turned on, gently at first, till iron appears at the tap-hole, which can then be closed and the full blast turned on. The first few ladles of iron should be used for inferior work. The various brands of iron should be evenly distributed, but some works use the whole pigs, as the advantages due to breaking them are not considered equal to the saving in fuel. A number of typical charges are cited to show the variations in practice at different works, giving the iron melted per lb. of fuel at 7 to 9.4 lbs. Too much iron should not be put in the first charge on to the fuel bed or the iron will run cold, but the total amount of iron charged should be as nearly as possible that required for the daily consumption.

Foundry Mixtures.—In a paper read before the Foundrymen's Association of Philadelphia, Mr. J. M. Warner † discussed the foundry mixtures in use in the United States. He points out that whereas five years ago most of the larger foundries used largely Nos. 1 and 2 foundry iron, with high-priced softeners, they now make their entire mixture with No. 2 foundry, No. 3 foundry, and grey forge pig iron, together with a little low grade silicon iron. The author refers to a large series of experiments made with a view to ascer-

* *Iron Age*, vol. xlix. pp. 728-729; *Iron*, vol. xxxix. pp. 384-385.

† *Iron Age*, vol. l. p. 61.

tain the best mixture to employ. About 150 distinct mixtures were tested. The bars broken transversely were 1 inch square and 24 inches between the supports. The strongest bar broke at 1923 lbs. It was composed of Southern coke iron, Ohio coke iron, scrap, and 1 per cent. of ferro-aluminium. The weakest broke at 840 lbs. It was made of a mixture of 50 per cent. each of old wheels and No. 1 Lake Superior iron, a well-known brand. Each of these two samples of iron was of admittedly high strength, and by mixing them together it was thought that a material would result which would yield a very strong casting for special work. The strongest bar obtained from a pig iron mixture, without ferro-aluminium, broke at 1530 lbs. This was from an all-coke mixture of a Southern and two Ohio brands. The general average of all the bars broken was 1120 lbs., with a deflection of from 0.25 to 0.53 inch. A comparison of these results would appear to show that red-short irons, that is, those low in phosphorus and silicon, when mixed together, make castings which are weak, hard, and liable to shrinkage, and to show blow-holes. Cold-short irons, rich in silicon and phosphorus, also tend to yield weak and hard castings when used alone. The best results are obtained by mixing in such a manner that the resulting casting shall contain about 0.75 per cent. of phosphorus, and 2 per cent. of silicon. The author refers to various mixtures of American pig irons which give such a desired result. Mill cinder has a tendency to soften the iron, and to render it more fluid, but it renders it "dirty," and impairs its strength, while the use of scrap, when it can be obtained lower than No. 3 strong pig iron, is to be recommended if carefully employed. As to silicon, the use of high silicon iron acts advantageously in nearly all mixtures, but the use of an excess of the silicon softener gives similar results to those resulting from the use of too little of that material, rendering the castings brittle and hard. Phosphorus increases the fluidity of pig iron, but induces hardness and brittleness, an excess must therefore be avoided. Sulphur exerts an almost directly inverse action on pig iron to that exerted by silicon, tending to lead to the formation of combined carbon, and to harden the metal. Its presence should therefore be avoided. Manganese also leads to the formation of combined carbon, and reduces the strength of the iron, but it makes it more fluid, removes shrinkage, and renders castings clean. With irons which carry much scrap, up to 1 per cent. of manganese is an advantage. The well-known Scotch irons contain from 1.5 to 3 per cent. of manganese. Combined carbon increases the hardness and brittleness of

cast iron. It is usually present when there is but little silicon in the metal. Indeed with over 1 per cent. of silicon it is difficult to produce a chill. The carbon in pig iron containing less than 1.25 per cent. of silicon is very sensitive to the least addition or decrease of silicon, as to the relative proportions of the combined and the uncombined carbon in the resulting castings. Graphitic carbon means softness, but an excess frequently leads to imperfections in the castings, and to the formation of blow-holes with inclusions of graphite.

Silicon in Foundry Mixtures.—Mr. W. J. Keep * observes that phosphorus and manganese in the percentages usually found in pig iron have but little influence on the metal, and do not influence the chill. Indeed, in some cases it would appear that the chilling tendency which some irons possess is independent of chemical composition, except that there is some curious relation existing between the carbon and the silicon. The greyness of the castings is entirely due to the silicon present. For very thin castings from $2\frac{1}{2}$ to 3 per cent. of silicon will give the best results. The larger the percentage of graphite after the iron is solid, the more fluid will it be in the molten condition, and this graphite is due to the silicon present. Phosphorus has been said to render iron fluid. This the author thinks is an inaccurate observation, but he believes that phosphorus causes the iron to remain longer molten. Silicon, by rendering the iron graphitic, reduces the shrinkage. It, too, reduces the tendency to chill, and it softens the iron. But silicon is lost during fusion in the cupola, and it is driven out of molten iron by sulphur, though the sulphur does not stay in the casting, but does the harm and then passes out. The silicon should be maintained at from $2\frac{1}{2}$ to 3 per cent. if an uniform soft grey product is to be made. As the percentage of silicon increases, so that of carbon diminishes, the casting growing lighter in colour. The grain, too, becomes less, and with 15 per cent. of silicon is usually absent altogether. Increasing the silicon beyond $2\frac{1}{2}$ per cent. usually does harm rather than good. Machinery castings should contain only about $1\frac{1}{2}$ per cent. of silicon.

The Chemistry of Foundry Processes.—Mr. J. Torry † discusses the influence of the foreign elements existing in or added to foundry pig iron on the character of the metal. He shows that silicon can be pre-

* *Iron Age*, vol. 1. p. 1126.

† *The American Machinist*, May, 12, June 9, 1892; *Iron*, vol. 11. p. 5.

sent in two different forms, one influencing the chill, and the other not acting in this manner. Similarly, too, phosphorus would appear to be apt to occur in more than one allotropic form. Then again the action of the various impurities is liable to be greatly influenced by their mutual presence. The author has made a series of experiments with a view to ascertain whether the chemical analysis could serve as a guide in judging as to the practical value of a foundry iron, and he decided that it could not. Indeed he considered that as far as the results of the tests were concerned the analyses were perfectly worthless, the indications, if any, being far too complex and obscure to be of any commercial value.

The Truesdale Cupola.—This cupola has five rows of tuyeres. In the bottom row are two tuyeres, each 3 inches in diameter; the second has fourteen 2-inch tuyeres; the third fourteen of $1\frac{3}{4}$ -inch; the fourth fourteen of $1\frac{1}{2}$ -inch; and the fifth an equal number, but of still smaller diameter— $1\frac{1}{4}$ -inch.

The tuyere openings are inclined towards the cupola bottom to prevent clogging, and the different rows are about $2\frac{1}{2}$ to 3 inches apart. The wind from the blower is conducted to the cupola by a pipe, and reaches the tuyeres through an annular space formed in the lining. There is a slag hole in the rear. The cupola stands 3 feet 6 inches above the floor level. The charging openings, two in number, are 12 feet 6 inches above the bed-plate, and about 2 feet 6 inches above the scaffold level. The cupola is designed to melt with coke and has melted about 9 to 1 in a cast of 20 to 24 tons for months continuously. The iron produced is very good, and the repairs necessary are inconsiderable.*

Moulding Cylinders in Dry Sand.—Mr. S. H. Leonard† gives a detailed account of the method of moulding a steam cylinder in dry sand at the Bath Ironworks. The cylinder described is 36 inches in diameter by 36-inch stroke, and is designed for a liner 1 inch thick. The pattern is of white pine, and a shrinkage of $\frac{9}{16}$ -inch per foot is allowed. The method of building up the pattern is fully described, and then a detailed account is given of the various kinds of sand employed and of the method of moulding. The cupola and its charge are also mentioned. The system was used for some fourteen cylinders, all of which were successful castings.

* *Iron Age*, vol. xlix. p. 869.

† *Journal of the American Society of Naval Engineers*, vol. iv. pp. 159-172, with three plates.

A similar detailed description is also given by Mr. G. H. Kearny* of the method of moulding in loam and casting the cylinders for the cruisers *Cincinnati* and *Raleigh* at the Navy Yard, New York. The work of building up the mould for one of the low-pressure cylinders is given at length. The mould for the exterior surface is first built up round a "dummy," which is then removed and replaced by a core. Full details of the sand, of the method of building, moving, and drying the moulds are given, and also of the actual casting process.

Contracting Chills for Cast-Iron Wheels.—The contracting chill for cast-iron wheels has now come into very considerable use, as shown by a committee report to the Master Car-builders,† though its value is still disputed. This form of chill is so arranged that it does not expand when the hot metal is poured against it. In some cases it is warmed before using, but in most forms it is cooled by the circulation of water or air, although other means of cooling are used. There are several forms in constant use. The committee above referred to has received the replies to a circular from some sixteen railways and thirteen wheel-makers relating to the form of chill they use, the subsequent treatment of the wheels, and the advantages or otherwise. It seems that an inferior quality of iron cannot be employed with advantage, but that probably more old material may be used.

Castings in Iron.—At a recent meeting of the Royal Institute of British Architects‡ four papers on the subject of castings in metals were read. Mr. H. Longden described casting in iron and brass, giving an account of the method of casting, with a description of the patterns, cores, and casting-boxes required. The necessary points to be observed in designing castings were mentioned, and the scope of the ornamentation and of the application of iron castings were discussed. Some account was given in the subsequent discussion of various ornamental and other castings that have been made.

The Reynolds Moulding Machine.—In this arrangement the sand is pressed into the flask by the aid of a lever. After filling the flask with sand, a presser-board is placed on top, and a presser-plate thrown into position above it, the presser lever being then brought

* *Journal of the American Society of Naval Engineers*, vol. iv. pp. 376-392, one plate.

† Meeting at Saratoga, New York, June 1892; *Engineering News*, vol. xxv. p. 665.

‡ *Proceedings*, vol. viii. pp. 319-327.

forwards to a position in which toggle arms operated by it are straightened to depress a swinging bail, drawing down the presser-plate and firmly packing the sand. The machine is so constructed that it can be placed on brackets or on a moulder's bench.*

Casting Sand.—F. Patrick † endeavours to render any ordinary sand suitable for foundry moulds. His process consists in bringing the sand to grains of uniform size, and then mixing it with coal tar or liquid asphalt. The tar is first heated and mixed with an equal quantity of hot water. This mixture is poured over the spread-out sand, which is then dried, and can be used for all foundry purposes. The proportions found to answer best in practice are 5 parts of tar, 5 parts of water, and 100 parts of sand.

* *Iron Age*, vol. xlix. p. 497, four illustrations.

† *Dingler's Polytechnisches Journal*, vol. cclxxxiii. p. 200.

PRODUCTION OF MALLEABLE IRON.

Iron Manufacture in India.—In an account of the iron manufacture of India, C. von Schwartz* describes the native methods of making iron. In Kerawli, Rajputana, a long, narrow reverberatory furnace is used. The fireplace has two openings for the nozzles of the bellows, and is fed with charcoal. The ore is arranged in heaps on the hearth, and is covered with fine charcoal. About 200 lbs. of ore is charged, and the blast is continued for six to eight hours. The bloom thus obtained is refined and cut up. The workmen say that during the cool east wind the yield of iron is greater than during the warm west winds. In the Kassia Mountains in Assam, fine magnetic sand from the brooks is washed, and then sticks and leaves are coated with it and dried in the sun. The sticks are then charged into the furnace. In Palamow, conical shaft furnaces built of clay are used, and the blast is supplied by foot-bellows.

Native Manufacture of Iron.—An illustration is given by Mr. J. T. Bent† of a furnace with the bellows and tuyeres used for the manufacture of iron at Kunzi's Kraal, situated in latitude 18° S. and longitude 31½° E., in South Africa. The furnace is a type of those used in a considerable district, and the industry is of great antiquity, being mentioned by Arabian writers close upon a thousand years ago. The furnace is somewhat of a flattened dome shape, with a short conical chimney, and open in front, with wings on each side of the opening, where it is rudely decorated. The ore, which contains much manganese, is obtained from the mountains and crushed. Charcoal is used as the fuel, and the goatskin bellows are worked by hand. The iron, when taken from the furnace, is worked with stone hammers.

The Springfield Ironworks.—At this ironworks, which is situated at Springfield, Illinois, the Henin gas process is in successful operation.

* *Zeitschrift des Oesterreichischen Ingenieur und Architekten Vereines*, March 18.

† "The Ruined Cities of Mashonaland," London, 1892, p. 268.

Five producers are in use, the by-products being utilised in the manufacture of ammonium-sulphate. A large number of puddling furnaces exist at these works, and, far from falling into disuse, they are being rebuilt, and a larger squeezer is being erected, all the main wearing parts of which are of steel.*

A Mexican Ironworks.—An ironworks is about to be erected at Chihuahua. It will comprise eleven puddling furnaces, with two scrap and two heating furnaces. Twenty-five nail machines will also be erected. This plant, which has been purchased in the United States, will be put up by American workmen.†

* *Iron Age*, vol. xlix. p. 612.

† *Ibid.*, p. 828.

FORGE AND MILL MACHINERY.

Ingot-Charging Crane.—A novel ingot-charging crane, designed by a firm near Leeds, has recently been illustrated.* It is intended for picking up ingots and charging them direct into the reheating furnace, and also for feeding the rolls with the heated ingots. It has five motions: travelling on the rails, charging and withdrawing the ingot, and also revolving, lifting, and gripping it. The charging arm has a travel of 10 feet, and can deal with an ingot $8\frac{1}{2}$ feet long and weighing 5 tons.

New American Plate-Mills.—A mill is being erected at Harrisburg, Pennsylvania, for the rolling of heavy plates. It is to be equipped with a set of rolls 34 inches in diameter and 132 inches long, driven by a compound Corliss engine with 28-inch and 54-inch cylinders and a 5-foot stroke. This mill will be 521 feet in length, and will enable the output of the existing plant to be increased from 50 to 300 tons.†

The largest plate-mill in the United States is that recently completed by the Wellman Iron and Steel Company, of Thurlow, Pennsylvania. It is served by heating furnaces, designed by Mr. S. T. Wellman. Along these runs a charging machine of special design, which delivers the ingots to the auxiliary feed-table, from which they are taken to the mill-table and rolled. The rolled plates are taken laterally to the shear-table by an overhead plate-conveyer. The three plate-mills are served by a 30-ton Morgan electric crane with an electric brake. This crane has handled the heavy housings of the train, which are greater in weight than the nominal capacity of the crane. Rolls can be changed in from eight to ten hours. A sheet of drawings relating to this plate-mill has appeared in the *Iron Age*.‡ The rolls are 132 inches long, the upper and bottom rolls $34\frac{1}{2}$ inches in diameter, and the middle roll 20 inches. The upper roll is held up against the screw

* *Industries*, vol. xiii. p. 133.

† *Iron Age*, vol. xlix. p. 828.

‡ Vol. xlix. p. 612.

by four counterbalance levers which pass through the foundations, the weights hanging in a pit outside. The middle roll is worked by a hydraulic cylinder through bell-cranks and their connections. Under the lower bearing at each end of the bottom roll is a wedge, the pushing out of which will lower the roll about half-an-inch. These wedges are worked by a 24-inch hydraulic cylinder, immediately under the roll, through two bell-crank levers. The rolls may thus be relieved instantly in case of accident. The screws are worked by a double direct-acting engine, the fine adjustments necessary in finishing the plate being made by hand. The table rollers are driven direct by a double horizontal engine. The engine driving the train is a Wetherill-Corliss engine with Porter bed-plate. The cylinder is 40 inches in diameter by 60-inch stroke. The train can roll plates 70 feet long, and is capable of producing any widths up to 126 inches.

Large Chilled Rolls.—The Farrel Foundry Company, of Connecticut, has made a pair of chilled rolls 31 inches in diameter in the rough and 156 inches long on the face. In the rough each weighed about 20 tons. They were cast solid and then bored out for their entire length to 5 inches diameter. Other and longer rolls have since been produced at this foundry.*

Rolling-Mill Engine.—Illustrations, including a side elevation and plan, of a new rolling-mill engine have been published.† The steam cylinder has a diameter of 24 inches, and the stroke is 36 inches; the working speed is seventy revolutions. The fly-wheel is 12 feet in diameter and weighs 6 tons. The crank-shaft is of mild steel 8 inches in diameter. Link motion reversing-gear with plain slide valves is used. The cylinder is cast separate from the steam-chest, and is lined with a separate cast-iron liner.

Large Ingot Extractors.—There are being manufactured at Gaysport, Pennsylvania, two ingot extractors, each of which will weigh 20 tons when completed, for use in the steel-converting department of the Cambria Iron Company at Johnstown. Each extractor has a hydraulic cylinder with a ram connection. An auxiliary cylinder and ram are attached to bring the former ram back into position after extracting the ingot from the mould. The bed-plate for this hydraulic

* *Iron Age*, vol. xlix. p. 305.

† *Engineering*, vol. liv. pp. 132-134.

machinery weighs 12 tons. Two wrought-iron bolts, each 10 inches in diameter and 17 feet long, connect the bed-plate and the hydraulic cylinders.*

The Schultz-Knaut Company's Works.—Some of the plant at the Schultz-Knaut Company's boiler works is illustrated.† This company buys steel but possesses sixteen puddling furnaces. There are nine boilers, 30 by 7 feet, in addition to which there are thirteen boilers heated by the puddling furnaces. Slabs and ingots are heated in six Siemens gas furnaces and four solid fuel furnaces. The two 5-ton steam-hammers have box girder wrought-iron housings. The principal rolling-mill is driven by two 36 by 54 inch cylinders. There are three pairs of housings, the rollers being 84, 115, and 138 inches long, the latter having a live roller feed. Four sets of shears are provided, the largest cutting-plates up to 1½ inch in thickness. Its blades are only 24 inches long; as it is often used for irregular forms the short blades are found more economical. The output is 1000 tons per month, about 300 tons being sold in a finished state. Machine-flanged boiler ends are made on a large scale. Corrugated flues are also made in a special form of bending-mill, which is fully illustrated by detail drawings. Water-gas is used when welding the seams.

* *The Johnstown Tribune*; through the *Iron Age*, vol. xlix. p. 828.

† *Engineering*, vol. liv. pp. 281, 288, 289, 291, 351-353.

PRODUCTION OF STEEL.

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I.—THE CARBURISATION OF MALLEABLE IRON.

Steel-Making in the Salem District, India.—In a report on the iron industry of Salem, Mr. T. H. Holland * states that, although at the present time both wrought iron and steel are being manufactured by pariahs in the Salem district, he nowhere found steel (wootz) being made in crucibles, as, according to previous writers, was the case when the industry was in a more flourishing condition. Wootz, however, is still being made in the adjoining district of Trichinopoly.

The process of manufacturing wrought iron is simply a very primitive form of the Catalan or Bloomery process. The process of smelting one bloom occupies two or three hours, the resulting iron weighing 18 lbs. The process of mining the ore is extremely wasteful. Only the well-disintegrated and rotten pieces of quartz magnetite schist are used. In dressing the ore, the large fragments are crushed with a flat hammer, and when sufficient material has been accumulated the crushed rock is winnowed by pouring out of a basket in a strong wind. Towards the end of the concentrating process the fragments which find their way to the lip of the basket are compound grains of quartz and magnetite. These are dropped back upon the pile for recrushing instead of being thrown away with the quartz waste. When the magnetite is well concentrated it is taken in this state to the furnace, but has still to be recrushed and sifted before it is fit for smelting. The last process is carried on near the furnace.

* *Records of the Geological Survey of India*, vol. xxv. pp. 135-159.

The method of making steel by the carburisation of wrought iron in crucibles is in vogue in Trichinopoly where the conical ingots of wootz are still made, whilst the flat cakes of steel now being made in the Salem district are produced by the partial removal by oxidation of the carbon in cast iron. In the manufacture of wrought iron in Salem certain easily fusible beads of iron are produced and melt off as shot. These are in reality highly carburised particles, and it is from these that the steel is made. The beads are first pounded in a stone mortar with a wooden pole guarded with an iron ring, the powdered slag material being separated by sifting. A hole is dug in the ground about 1 foot deep and 1 foot in diameter, and at one side a semi-circular groove is excavated from the surface of the bottom of the pit. A large cake of soft clay serves to divide this small excavation from the other part of the pit, and the smaller chamber serves as the finery in which the steel is made. The bottom of this is first covered with a layer of dirty quartz obtained from sifting the crushed ore. There are generally pieces of magnetite adhering to this quartz, which fact accounts for the particles of ore in the steel produced. On this hearth of quartz an ignited coal is placed and the chamber filled with charcoal. A tuyere, previously built in with the clay partition, points downwards at an angle of 45° , and receives the nozzles of two goat-skin bellows, by which a continuous blast is maintained. The beads are first wetted and then thrown upon the charcoal, the amount used being determined by guess-work. The blast is continued for half an hour when the process of decarburisation is complete, and the tuyere and clay partition broken down for the removal of the steel cake, which is first slightly cooled by a dash of water, and then hammered to remove the casing of slag which has formed around it. The cakes of steel are sold for four or five annas each.

In the Salem district iron-smelting is confined to the Salem, Trichengode, and Attur taluqs. At most of the places where smelting is, or has been, carried on, large heaps of ashes and slag, 10 to 20 feet high, were noticed, with, in one or two cases, trees of a foot or more in diameter growing on them.

Steel Castings.—A. Ledebur * discusses the paper on this subject read by Mr. H. L. Gantt before the American Institute of Mechanical Engineers. In that paper reference was made to various objections which have been raised partly as regards the trustworthiness of steel

* *Stahl und Eisen*, vol. xii. pp. 401-405.

castings, and partly as to the difficulty of obtaining an accurate casting. The author suggested that the metal should be cast as hot as possible, but the accuracy of this advice is doubted by Ledebur. Next, Gantt states that the casting must be very carefully annealed, a heavy scale resulting, which leaves the surface of the casting rough. Ledebur observes that this heavy scale is probably due to faulty annealing, as he has seen many German steel castings with an extremely good surface after annealing. To allow for contraction Gantt suggests an allowance of from $\frac{1}{84}$ to $\frac{1}{16}$, and with heavy castings $\frac{1}{66}$ inch, and for the mechanical treatment of heavier castings from $\frac{1}{4}$ to $\frac{1}{2}$ inch. The question of blowholes is also referred to, and Ledebur points out that in good castings the percentage of silicon rarely exceeds 0.3 and that of manganese 0.8, and as the extreme admissible limit for castings containing 0.5 per cent. of carbon, 0.6 of silicon, and 1.2 of manganese. To obtain a good casting the upper parts should be the thicker, and the head should be large, and, to avoid cracks on cooling, as simple shapes as possible should be employed, and at the dangerous places an iron bracket or pin should be placed to cause the more rapid solidification of the metal. The metal of unannealed steel castings resembles over-heated hammered steel, but annealing toughens it. To prevent too rapid wear hard metal should be used for the casting; but this has a tendency to show blowholes. Silicon and manganese should be added to prevent this, but an excess of these elements is dangerous. The percentage of carbon should vary from 0.6 downwards, according to the use to which the casting is to be put.

II.—THE OPEN-HEARTH PROCESS.

The Schönwald Open-Hearth Furnace.—At Friedenshütte, Germany, an open-hearth furnace was remodelled on the Schönwald system. It went into work on November 14, 1891, and was never out of fire until July 11, 1892. During this period it made 712 charges in 205 working days of 24 hours, the production amounting to 8562 tons of ingot metal, chiefly very soft. The daily outturn was thus 40.8 tons. In 594 charges the metal produced had less than 0.1 per cent. of carbon, and only 15 of the total 712 resulted in metal with more than 0.2 per cent. of carbon. The average campaign before reconstruction did not exceed more than 200 charges.*

* *Stahl und Eisen*, vol. xii. p. 759.

New Form of Open-Hearth Furnace.—Drawings are published* of an open-hearth furnace erected at the works of the Linden Steel Company, Pittsburgh. It is intended that natural gas shall alone be used in this furnace. A number of difficult conditions had to be met when designing the furnace. Especial care was given to the design of the regenerative chambers, which are horizontally arranged, the reversing-valves being placed low enough to secure a good natural draught and to obviate the use of blast.

The Noble Gas Furnace.—Illustrations are published† of an open-hearth furnace erected in California, and so constructed as to be adapted to a space more than usually cramped. The valves are directly beneath the hearth; the air and gas flues leading from the valves to the regenerative-chambers course direct. In ten hours the fireman heats in this furnace 175,000 lbs. of cold 16-inch ingots, and produces 147,000 lbs. of 7-inch blooms, not including clippings. It is thought that with the aid of a new charging-machine the output of blooms will be increased to 184,000 lbs. in ten hours. The furnace is served by six Wellman gas-producers.

Tipping Open-Hearth Furnace.—A section of a tipping open-hearth furnace, designed by Messrs. H. Aiken, F. W. Wood, and H. H. Campbell, has been published.‡ The hearth is built on a metal framework with a lower curved side running on a series of free rollers. The ports are arranged on the axis of the furnace, so that their area does not vary as the furnace is moved.

An Open-Hearth Furnace Record.—What is stated§ to be a record performance for an open-hearth working with producer-gas and light scrap has been recently made by the No. 4 open-hearth furnace of the Phoenix Ironworks, Phoenixville, United States. In six days this furnace made eighteen heats of under 0·14 carbon steel, using 33 per cent. of pig iron. It is a 20-ton furnace, and the total output in the six days referred to was 389 tons.

The Carbon Iron Company, Pittsburgh.—At these works a new plant is being erected which includes two 25-ton open-hearth

* *Iron Age*, vol. xlix. p. 857, four illustrations.

† *Ibid.*, vol. l. p. 101, three illustrations.

‡ *Engineering and Mining Journal*, vol. liv. p. 293.

§ *Age*, vol. xlix. p. 675.

furnaces, the present plant including two 15-ton and two 30-ton furnaces. A new 3-high plate mill is to be 124 inches long and 34 inches in diameter, capable of rolling plates from 2 inches to $\frac{1}{4}$ inch in thickness; the cooling tables for cooling the plates will be 375 feet long. The adjusting-screws of the mill are to be operated by electric motors. A lifting or tilting table will also be erected to enable the bottoms of the plates being inspected before shearing. No such appliance, it is thought, is in use for this purpose at any other works. Three 3-hole soaking-pit furnaces will be put in, each hole measuring 4 feet 6 inches by 6 feet 6 inches. The shear for cutting the plates will have 136 inches gap, and will be capable of cutting plates 120 inches long by 2 inches thick. An electric travelling-crane will span the soaking-pits, another will be erected over the 3-high train and engine for changing the rolls, and a third will be erected in the shipping department to permit the ready handling of heavy materials. The electric cranes are of the Shaw type. The dynamos will be of over 200 horsepower. When in complete running order the works of the Carbon Iron Company with this additional plant will be able to turn out from 275 to 300 tons of plates per day.*

A New American Steel Foundry.—The Penn Casting Company of Chester, Pennsylvania, are largely increasing their existing plant. A complete modern steel-casting plant, with all the most recent improvements, is being fitted; the foundry is being enlarged to the extent of 245 by 100 feet, while an addition of 40 by 40 feet is to be made to the engine and boiler house. A new gas-house, 40 by 48 feet, is in course of erection; two 15-ton open-hearth furnaces and six gas-producers are being built, as well as four large drying-ovens; and two 25-ton electric cranes will be placed in the workshops.†

Basic-Steel Castings.—These are now being made by the St. Louis Steel Foundry Company.‡ The company first began to make steel castings by the crucible process, which they found so slow that they went to the other extreme and put in a Bessemer converter. But the steel-casting business was found to be unsuited to a steel-converting process, which required a continuous output in order to secure good economic results. The open-hearth furnace was then substituted, and was found to come closer than any other process to the results desired. In regular work, however, unexpected troubles were

* *Iron Age*, vol. xlix, p. 675.

† *Ibid.*, p. 879.

‡ *Ibid.*, p. 614.

encountered. Although the best grade of pig iron was used, very low in phosphorus, the castings after a time became so brittle that there was much complaint. On thorough investigation, based on analyses of the material treated at every stage, it was ascertained that the very small contents of phosphorus originally in the pig iron were never lost. The gates and risers being much greater than in iron castings, and being put back in the furnace with each fresh charge, contained a larger percentage of phosphorus than did the original pig iron, in consequence of the diminution in bulk through waste. The result was that the contents of the furnace were growing richer in phosphorus with every fresh charge. Open-hearth steel blooms, specially low in phosphorus and necessarily high priced, were purchased to overcome this trouble, and formed part of the charge; but the trouble was not surmounted. It was found, as has been reported by other experimenters, that the phosphorus would segregate and be found in greater abundance in some castings, or in some parts of a casting, than in others, causing great irregularity.

The material now used in the basic open-hearth belonging to this company is Tennessee charcoal pig iron, containing about 0.05 per cent. of silicon, from 0.2 to 0.3 of phosphorus, and but little sulphur. The steel castings produced from this metal contain only from 0.02 to 0.05 of phosphorus, and this percentage would be still lower were it not for the phosphorus contained in the ferro-manganese employed. The open-hearth used takes a charge of 9000 or 10,000 lbs. The dolomite used for the furnace lining is from Tennessee. It contains but very little silica, about 54 or 55 per cent. of calcium carbonate, and 41 of magnesium carbonate. When calcined it is ground and then mixed with tar. In casting, a ladle is used of sufficient size to take the whole contents of the furnace, the ladle being first heated to a white heat by means of an oil and air burner, as the castings made are usually very low in carbon. All castings are annealed, and these are found to give excellent results when submitted to mechanical test.

The Wellman Heating Furnace.—Full drawings of this furnace appear in the *Iron Age*.* The furnace is of the ordinary Siemens type, but with some modifications. Only one half of the regenerator is below the furnace. The valves are aboveground, and are placed outside the main building. They are single poppet valves of the Hyatt type, and are worked by small compressed air cylinders placed immedi-

* Vol. xlix. pp. 820-822, five illustrations.

ately over the valves and connected directly with them. The large doors of the furnace are also lifted by compressed air. The furnace beds are 31 feet 3 inches long by 7 feet in breadth. Each furnace has three doors each 7 feet in length. The roof is very high from the bottom, and the two furnaces at the works at Thurlow, Pennsylvania, have turned out over 100 tons in twelve hours, the ingots being charged into the furnace cold, and being in most cases heated nearly to a welding heat. The producers used at these works are the ordinary circular producers of the Wellman type.

The Walrand Process.—The Walrand-Legénil process is stated to be in active operation at the Legénil Foundry, Paris. A 550-lb. charge of metal is blown for from eight to twelve minutes, 5 per cent. of ferro-silicon, containing 10 per cent. of silicon, is then added, and the blowing continued for a minute or a minute and a half, when the charge is poured.*

III.—THE BESSEMER PROCESS.

The Acid Bessemer Process.—A. Kayser † discusses the question as to the linings of acid converters. At the works of the Sociedad de Altos Hornos, at Bilbao, the difficulty is the greater in that all the fire-resisting material required at the works is brought from the United Kingdom. The author's endeavour, when engaged as the manager of the steel-making department at these works, was to lengthen the life of the bottoms and of the lining of the converter body. For this purpose it was necessary to consider what were the substances which attacked this lining in addition to iron and manganese. If these were the only substances present in the iron charged into the converter which attacked the lining, then that pig iron made at the works which contained the largest quantity of manganese should have had the most destructive effect. This, however, was far from being the case, and the author was finally led to the conclusion that there must be some other attacking agent present in the pig iron. Analysis, as he anticipated, proved the presence of both calcium and magnesium. The iron was not examined for oxygen, so that it is just possible that both the calcium and the magnesium may have been present in the iron as

* *Iron Age*, vol. xlix. p. 448. See *Journal of the Iron and Steel Institute*, 1892, No. I., p. 431.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 255-258.

entangled slag. Still the author does not believe this to have been the case, and he points out as a reason for his belief that the ratio borne by the magnesium to the calcium in the iron was frequently greater than that existing in the slag from the blast furnace. Another cause for his belief lay in the observations made during the blow. The metal was taken direct from the blast furnace, but the percentage of silicon present was liable to great variations, and the blow was watched by a spectroscope. As is well known, when the blow is a very hot one, the so-called carbon lines are not discernible. The regulation of the blow was consequently a matter of some difficulty. Besides other points, it was customary for the blower, if certain red lines to the left of the sodium line were not to be observed, to keep on adding cold scrap until these lines became visible. In a hot blow calcium does not burn, but this happens when the blow is cold or has been cooled down. Consequently, the author considers that the red lines above referred to, which become visible on the left of the sodium line, are in reality due to calcium. The author illustrates his remarks by a number of curves, giving the percentages of the various elements present in the metal during the several stages of four blows. Details relating to these charges are also given.

Steel Casting-Ladle.—Drawings are published * of a casting-ladle made recently at Duisburg. The ladle itself will hold about 7 tons of steel, while the total weight of the whole apparatus is about 14½ tons. The pan is so arranged as to be impossible for it to tip by itself. The motor engine is of the vertical twin reversing type.

The Atlas Steelworks.—In connection with a visit of the North East Coast Institution of Engineers and Shipbuilders to these works, a plan of them is published in *Industries*.†

Basic Plant at the Domnarfvet Steelworks.—At Domnarfvet, in Sweden, the old Bessemer plant, consisting of three 5-ton converters, has been increased by the addition of five new converters, three of which are designed for the basic process. The basic plant was started on October 26, 1891, with iron containing—

Manganese.	Silicon.	Sulphur.	Phosphorus.	Carbon.
0.5-0.75	0.5-0.75	0.02	2.5-3.0	3.5-4.0

obtained from apatite-bearing ores from Grängesberg.

* *Stahl und Eisen*, vol. xii. p. 646, with plate.

† Vol. xiii. p. 8.

Of the Grängesberg ores, 70,000 to 80,000 tons are annually exported to Silesia, and a similar amount to Westphalia,* the composition of the ores being as follows:—

Silica	2.65	2.76	6.07	2.06
Ferric oxide	59.20	79.64	57.56	63.90
Ferrous oxide	27.40	9.64	26.26	29.11
Manganous oxide . . .	0.36	0.14	0.24	0.06
Alumina	2.85	1.29	1.58	1.82
Lime	3.24	3.38	3.39	1.98
Magnesia	0.94	1.41	2.07	0.64
Phosphorus	0.98	0.88	0.87	0.54
Sulphur	0.07	0.01	0.04	trace
Iron	62.78	64.02	60.56	67.38

Basic Slag as a Fertiliser.—According to Mr. W. H. Morris,† the Potlstown Iron Company is the only one manufacturing basic Bessemer slag in the United States. They grind the material so that at least 60 per cent. will pass through a sieve with 150 meshes to the linear inch, and 90 per cent. through a 100-mesh sieve. This fine grinding seems to be the main conditions of success. Its value for grass and other produce is testified to by the author. From 300 to 700 lbs. per acre should be used, together with potash-yielding material. Its beneficial effect is not seen till the second and third years. The basic open-hearth slag at these works is not so well adapted as the Bessemer slag, which carries over 20 per cent. of phosphoric anhydride.

IV.—OTHER PROCESSES.

The Talbot Process.—In this American process a basic oxide of iron and lime slag is made and mixed in a regenerative gas furnace, and is then poured into a vessel so constructed as to form a deep column of slag. Then the molten pig iron to be treated is poured on the top of this column of slag, through which it sinks, and it is stated that during its passage a considerable quantity of the silicon is removed, together with some of the carbon and also of the phosphorus. The metal so treated is transferred to a basic open-hearth, and the process completed in the ordinary way.‡

* *Zeitschrift des Vereines Deutscher Ingenieure*, vol. xxxvi. p. 139.

† *Transactions of the American Institute of Mining Engineers*, Baltimore meeting (advance proof).

‡ *Iron Age*, vol. l. p. 102.

Manufacture of Nickel Steel.—The Lechesne process for making nickel-steel alloys consists in the simultaneous employment of nickel, manganese and aluminium with or without carbon. Both the nickel and the aluminium may be used in the pure state, or in the form of alloys or otherwise, and the manganese is similarly employed. As an example, the following amounts may be used :—

Pig iron with 25 per cent. of nickel	100
Malleable iron or steel	400
Ferro-manganese with 75 per cent. of manganese	3
Aluminium	0.25

The ferro-manganese is added after decarburisation, and the aluminium at the moment of tapping. The alloys are homogeneous, and solidify rapidly without blowholes. Ferro-nickel, with 25 per cent. of nickel, cannot be hardened, but this property appears when the nickel is lowered below 5 to 7 per cent.*

* *Iron*, vol. xxxix. p. 360.

FURTHER TREATMENT OF IRON AND STEEL.

A Primitive Method of Iron Working.—In a report* of the Canadian Institute, there is figured an iron tomahawk, which has been submitted to a very primitive method of working. It is of a type common in the country, and bears marks of an attempt by its owner to reduce its weight by the laborious process of cutting a strip off it with flint flakes and water. There is also a strip in the collection which has been cut off in this manner. The tomahawk measures $7\frac{1}{2}$ inches in length by $1\frac{1}{2}$ inch in thickness near the eye.

Annealing Tool Steel.—At the works of Messrs. Saunders' Sons, New York, all steel to be made into cutting tools or dies is heated in a coke oven to a red heat, the bars being then removed and placed in a second heating-chamber, consisting of a simple brick chamber, in which the bars are arranged in layers separated by charcoal. Here they are allowed to remain undisturbed until perfectly cool. Steel so treated improves in quality.†

A Large Casting.—A cog-wheel of large size has been cast by the Economy Foundry Company of Syracuse, New York. The wheel is 11 feet in diameter, the face is $10\frac{1}{2}$ inches in breadth, and the pitch $4\frac{3}{4}$ inches. It was cast in eight sections, with sectional gear at the centre. The whole weighs 5 tons, and the gear is claimed to be the largest, with one exception, that has ever been cast.‡

Wrought-Iron Chimney.—What is stated to be the tallest wrought-iron chimney in Great Britain has been erected at Darwen in North Lancashire. It is 275 feet high from its foundation to its top, and is used for carrying off the gases from the blast furnaces of the Darwen and Mostyn Iron Company. Sixty tiers of plates are

* *Annual Archaeological Report*, 1891, p. 51.

† *Iron Age*, vol. xlix. p. 1217.

‡ *Ibid.*, p. 253.

employed in its construction, 308 plates being used. The base plate is in six segments, and is $27\frac{1}{2}$ feet in diameter. The brickwork lining is 18 inches in thickness at the bottom and 3 inches at the top. The total weight of the ironwork employed is 114 tons 7 cwt., and took eleven weeks to erect, while the total weight of the chimney is about 1100 tons as compared with 3000 tons for a brick chimney. Several other iron chimneys exist in England, and in America there are a considerable number.*

Electric Welding.—In the arc process of electric welding there are three distinct methods in use. The first of these is welding, properly so called, in which the material to be welded is raised only to the welding temperature, and a strong fibrous weld is produced. In the second method of "built welds" small pieces of the metal are melted into the joint and hammered in. The fibre is then partly reproduced by the work put into the metal. A special grade of very mild steel has proved most useful for this work. The third method is chiefly used for repairing castings, and is not well adapted for wrought iron or steel. It consists in filling the defective parts with metal fused by the arc, which also melts the work locally. In the case of cast steel the article may be hammered. Articles of cast iron can only be treated by keeping the whole black hot during the process. Examples of the process of welding are given.†

N. Slaviankoff ‡ describes a method devised by him for electrically welding and repairing broken pieces of machinery. The work to be repaired is attached directly to one pole of a dynamo, and the metal to be cast is melted by the electric arc in a special tool, and falls on the object in a molten state. A description of the tool is given with the aid of drawings, and also directions for and the cost of different kinds of work. The difference between this and the Bernardos process is pointed out.

Pipe-Welding Machine.—Drawings are published § of a machine for rapidly welding the overlapping portions of a coiled strip of sheet metal, so as to produce a pipe having a spirally welded skew. The main frame of the machine has bearings for a shaft, which projects beyond the frame, and carries a roll which constitutes the internal winding

* *The Engineer*, vol. lxxiv. p. 412.

† *Electrician*, vol. xxix. pp. 335-336.

‡ *Ghormui Zhurnal*, 1892, p. 14.

§ *Iron Age*, vol. I. p. 422, three illustrations.

roll, its periphery bearing upon the inside of the pipe or tube at the point where the weld is to be made. There is a second and external welding-roll, which has a slightly coned or bevelled face, and which bears upon the pipe at a point immediately above the internal welding-roll. The metal is heated to redness before reaching these rolls, and then, by a combined pressure and "wiping" action of the outer roll, the welding is effected, and its exterior bevelled or reduced to a feather edge, and objectionable ridges prevented upon the outside of the pipe.

Wire-Rod Rolling.—According to Mr. R. W. Hunt,* the Germans were probably the first to roll wire rod by plain rolls, which forced the work through dies. Grooved rolls were, however, soon adopted, but it was not until mild steel replaced wrought iron that much progress was possible. The Belgian mill made the first great advance. In this arrangement the billet is passed several times through slow-driven roughing rolls, and then passed to the finishing rolls, placed at some distance from the first set. At first only hand labour was employed, but mechanical appliances were introduced to reduce the number of men required. In 1869 the Bedson mill was erected. In this there is a pair of rolls for each groove, and each pair is driven faster than the preceding one, to take up the slack due to the elongation of the metal. All the rods are in line, and the axes of the alternate rolls are at right angles, to avoid turning the bar. Continuous mills could not work successfully till mild steel was used, as the wrought iron is not sufficiently uniform. The next improvement was in the use of the power-reel instead of the hand-reel for coiling the product. By driving the reel from the rolls as much as 50 feet per second can be finished. The bed of the reheating furnace was also lengthened to take billets up to 21 feet in length, and the size of the billets has been increased to as much as 4 inches square. Some records of the speeds and outputs attained are here given by the author. A departure was made by Mr. Morgan from the original form of the Bedson mill by putting the axes of all the rolls in a horizontal plane, and by turning the rod between them, so that the construction is simpler. The Garrett mill is an extension of the Belgian mill, and is designed to do away with reheating the billets by rolling direct from the ingots. For this purpose three sets of rolls are arranged in echelon, and are driven at progressively increasing speeds. Not only can larger billets be used

* Lecture delivered at Cornell University, February 26, 1892; *Iron*, vol. xxxix. pp. 332-334.

in this way, but several may be in the rolls at the same time. In all the later forms of mills, except those of the continuous type, use is made of the "repeater," which is a device for automatically turning and transferring the work from one pass to the next. Several types are in use, and there is some discussion as to whom the credit of the first form is due. Some details of American mills and of their production are given.

The Turk System of Wire Rolling.—D. Turk* describes a system of rolls which he has devised for the purpose of increasing the capacity of a wire-rolling mill, admitting of the automatic passing of oval as well as of square rods from one pass to another. It was desired, in designing these rolls, to avoid some of the disadvantages of existing wire-mills, especially the use of hand labour in the case of oval rods, that of keeping the diameter of the rolls well under control, and also to admit of greatly increasing the speed at which the rolls can be driven.

Continuous Wire-Drawing Machines.—The wire-drawing machines of the Waterbury Machine Company, Connecticut, are illustrated in the *Iron Age*.†

A pedestal is surmounted by a framework which carries the several drawing blocks, and along the upper surface between the three rows of blocks, 3 inches in diameter, are the lubricating rollers. At the point where the wear comes the blocks are provided with removable rings of hardened steel or of chilled iron, which can be easily renewed; they are all driven at the same speed. The finishing block is 7 inches in diameter, sometimes 8 inches, and is driven at the same surface speed as the small blocks. The lubricating device consists of two cylinders, which extend the entire length of the trough containing the lubricant; their lower surface dips into the liquid, and, as they revolve, brings up a surface coating, keeping the die-holders, which are between the rolls, full to overflowing at all times. The die-holders are placed in a single row, central with the machine, and when the dies are dropped into the receiving pockets the diamonds are submerged and are safe from fracture by heating, and are thoroughly lubricated. At the back of the machine is placed the usual reel holder, which is adjustable in position along the frame.

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 431-432, with six illustrations.

† Vol. xlix. p. 651, with two illustrations.

The end of the wire as it comes from the reel is pointed by filing in the case of the larger sizes, or by stretching in that of the finer sizes, and its reduced end is then threaded through the largest die in the series.

The Works of the Pittsburgh Wire Company.—The works of the Pittsburgh Wire Company is situated at Braddock, Pennsylvania, ten miles from Pittsburgh. The main building, in which is contained the rod-mill and wire-mill, is 125 feet wide by 400 feet in length. The rod-mill is of the continuous mill design, and contains a 16-inch and a 12-inch billet train, as well as a 9-inch finishing train. The 16-inch and 12-inch trains are driven by a 36 by 48 engine, which is expected to develop 1600 horse-power, while the 9-inch train is driven by a 20 by 24 automatic engine of 500 horse-power. The fuel used is producer-gas, furnished by four Taylor gas-producers, operated in connection with two Morgan inclined heating-furnaces for heating billets. The boiler-house is immediately adjacent to the rod-mill, and is equipped with 2000 horse-power Babcock & Wilcox boilers, with mechanical stokers. The capacity of the mill is 150 tons of wire rods every twenty-four hours. The wire-mill will be equipped with 96 wire-drawing blocks, driven by two 20 by 24 engines. All the buildings are of corrugated iron.*

Forging and Stamping.—In the course of some notes on the manufacture of iron, Mr. H. Webb † describes the method of making slabs, and the operations of faggoting and shingling puddled iron and scrap. The method of building up a large crank shaft from the wrought-iron slabs is also described in detail. To make good forgings there should be good furnaces, strong cranes, double-acting steam hammers, and steady workmen. The furnaces are usually of the reverberatory type with open or closed grates, or are regenerative gas-fired. Stamping is very largely used for small articles especially, and hydraulic forging for heavy work. Both these operations are described in some detail.

Flanging Machines.—An improved flanging machine is illustrated ‡ in which a plain instead of a conical roller is used to produce the flange on boiler flues. This roller runs on a pin fixed in a frame which

* *Iron Age*, vol. xlix. p. 344.

† Paper read before the Manchester Association of Engineers, February 27, 1892.

‡ *Industries*, vol. xiii. p. 420.

1892.—ii.

swings on two axes placed at right angles to those of the bottom roller. The appliance can be adapted to any machine.

Planing, Shaping, and Milling Machines.—A plate-edge planing machine of Manchester make is illustrated.* It will admit plates of any length, and will cut 16 feet at one stroke. The tool saddle carries a platform for the attendant, and works on a bed 20 feet long. The cramping girder and housings are of box sections.

An illustration is also given † of a specially designed combined horizontal, vertical, and transverse planing and slotting machine, adapted for cylinder, cranks, and wheel work.

Armour-plate planing and slotting machines for the United States have been built by a firm at Leeds. One of them, of which illustrations have been given, will take work 30 by 10 by 5 feet.‡

A large planing machine, designed on what is known as Sellers' principle, is illustrated.§ Helical gear, automatic lubricators, and an improved arrangement of belt shifting-gear have been applied.

The open side planer for steel, made by the Detrick and Harvey Machine Company of Baltimore, Maryland, is driven on the Sellers' principle. The pulley-shaft is parallel to the bed of the planer, and the cross-beam is supported by a brace rigidly bolted to the back of the post, which is of heavy construction. The post takes a bearing on the bed equal in length to one and one-half times the amount of overhang of the beam. The head on the beam has automatic feeds in all directions. The beam and brace are raised and lowered by power. The bed is half as long again as the table, and both the bed and table are of massive construction.||

The Niles shaping machine is of the travelling-head type, that is to say, the saddle carrying the cutter-bar is traversed on a bed of considerable length, the cutting-tool operating at all points. The cutting-tool is arranged with the Whitworth quick return, and so that the forward or cutting stroke takes about two-thirds of the crank motion, the return stroke being made during the returning third. A coned pulley, with wide belts, is employed to determine the speed of the cutter-bar.¶

A large slotting-machine is illustrated in *Engineering*.** The tool has a stroke from 42 to 48 inches, and the table has a vertical adjust-

* *The Engineer*, vol. lxxiv. p. 126.

† *Ibid.*, pp. 394 and 400.

‡ *Iron Age*, vol. xlix. p. 665.

** Vol. liv. p. 80.

† *Ibid.*, pp. 149 and 155.

§ *Ibid.*, vol. lxxiii. p. 407.

¶ *Ibid.*, p. 721. one illustration.

ment of 30 inches. The tool weighs 30 tons, and the main part of the frame is made in one casting, without exceeding the limits for railway transport.

In the Niles slotting machine the cutter-bar has a length of 10 feet and a stroke of 54 inches. The machine will take in work up to 10 feet in diameter. The diameter of the circular table is 66 inches, the longitudinal traverse of the table 60 inches, and the side traverse 50 inches. The guide for the cutter-bar lowers to within 18 inches of the table, and raises to 56 inches above the table. The cutter-bar is driven by rack and pinion, adapting it for heavy cutting. The machine has sufficient power to take a 3-inch cut with a $\frac{1}{16}$ -inch feed. The cutter-bar is counter-weighted and has a quick return. The rated stroke of the machine is 54 inches, but on outside work, which can be placed in front of the cutter-bar, a cut nearly 9 feet in length can be taken. The feeds are self-acting in all directions, and are readily adjusted.*

The milling machine designed by Mr. P. J. Kelly,† of Elizabeth, New Jersey, has a modified arrangement for feeding the work to the cutters, and adjusting the cutters themselves. The pedestal of the machine is provided with standards in which a cutter-carrying shaft is journaled. Upon this shaft is a pair of cutter-heads spaced by means of an intervening sleeve, and forced against a shoulder on the shaft by means of an adjusting nut. The standards are formed with arms in which the driving-shaft is mounted. Extending from the front to the back of the machine, in a direction transverse to that in which the cutter-shaft extends, is a feed-screw, which, with its supporting frame, is a short distance on one side of the inner cutter-head, thus leaving a free space for the travel of the work between the two cutter-heads. The feed-screw is operated by means of a worm-wheel engaging with a worm on a shaft driven by a belt. This worm is so mounted that it may be swung into and out of gear with the worm-wheel, thus admitting of the feed-screw being turned by means of the crank-handle. The material to be operated on is placed on a frame consisting of two sections so united that vertical adjustment is possible by lengthening or shortening the frame. This adjustment is accomplished by means of bolts through elongated slots in one frame. The cutter-heads are of cast iron, and the cutters are held firmly in position by a ring, through which set-screws extend and bear against the backs of the cutter-shanks, holding these firmly in place.

* *Iron Age*, vol. xlix. p. 555, one illustration.

† *Ibid.*, p. 289, three illustrations.

Mr. W. D. Shaw * states that he is always able to harden large milling-cutters successfully. He heats them slowly in a covered, slow forge fire of coke without flame, being of opinion that the reason for teeth cracking off is that they are made coarse and weak in grain by jets of hot air in a brisk fire. Sufficient time is given for the cutter to soak to a clear, uniform, hardening heat, and when no portion is visibly hotter than another it is dipped in a large water-bath of a temperature of 60° or 70°, and moved slowly downwards until the cutting parts are hardened. It is then rapidly removed and heated for a moment over a bright fire to relieve the strain of the contracted rim upon the hot centre, and then again dipped into the bath to prevent the teeth from drawing. This operation is repeated several times, the number depending upon the size of the cutter, the object being to relieve the strain while retaining the hardness. The piece under treatment is finally plunged into hot water and left until the steel has become of the same temperature as the water, when the temper may be drawn in the usual way. The author states that by following this method of operation he is always able to successfully treat shapes however difficult or irregular.

Boring and Turning Machine.—A description is published † of a machine of this type manufactured by the Niles Tool Works, Ohio. A single casting forms what would otherwise be the bed, housings, and top brace. The column is so shaped as to partially surround the table, orifices being left for the admission of light. The driving-cone is at the back of the machine, the motion being transmitted through bevel gearing, the cone being back-gearred, and with two speeds available from countershafts, affords sixteen changes of speed to the table. The cross-rail is bored out in box-girder form with wide bearings, and is counterbalanced by weights suspended in the interior of the column. The saddles are made right and left, allowing the boring bars to work close together, these latter being of octagonal section and counterbalanced by a single weight. The feeds are operated by a friction disc.

A horizontal boring machine with two adjustable standards and boring spindles is illustrated in *Engineering*.‡ It is adapted for general work and can also be used for tapping.

Illustrations are published § of the turning and boring lathe con-

* *Iron Age*, vol. xlix. p. 809.

‡ Vol. liii. p. 694.

† *Ibid.*, p. 1211, one illustration.

§ *Iron Age*, vol. xlix. pp. 976-978.

structed by the William Sellars Company of Philadelphia for the Washington Navy Yard. It is intended for use in the manufacture of 16-inch cannon. The main bed is nearly 74 feet in length, by 9 in width, and 2 in depth. The support for the boring bench is 54 feet 5 inches long, 5 feet 2 inches wide, and 2 feet deep. The headstock carries three forged steel spindles. Full construction details accompany the illustrations.

Cutting and Punching Machines.—A combined punching, shearing, and angle-iron cutting machine is illustrated.* It will punch $1\frac{1}{2}$ -inch holes through mild steel plate $1\frac{1}{2}$ inch in thickness at 30 inches from the edge, and will cut angle iron 8 by 8 by $3\frac{1}{4}$ inches. Two $2\frac{1}{2}$ -ton jib cranes are mounted on the machine. The framework is of box section, and the various slides can be worked independently. The machine weighs 40 tons.

An illustration is published of an American punching machine, the design being such as to deal with heavy work. The machine has a stroke of $1\frac{1}{2}$ inch, and will punch to the centre of a circle 100 inches in diameter, and will also punch a $3\frac{1}{2}$ -inch hole through a $\frac{3}{4}$ -inch steel plate. The flywheel revolves freely on the shaft at the rate of ninety revolutions per minute, and when pressure is applied to either the handle-bar or the foot-treadle an automatic clutch is operated to form a very rapid connection between the shaft and the flywheel. If the foot be removed from the treadle as soon as the shaft has started, only one stroke will result, the slide carrying the punch stopping automatically at the highest point, the movement being continuous if the foot is kept on the treadle.†

The Manufacture of Horse-Shoes.—The Rhode Island Perkins Horse-Shoe Company manufactures horse-shoes mainly from old iron and soft scrap, and for steel shoes steel billets some 2 inches square are used.‡ The rolling-mill contains three muck and six finishing trains. The stock is sheared and piled; the piles are then rolled on an 18-inch muck-train driven direct. It has three stands, one 3-high, in which five passes are made, one intermediate 2-high for one pass, and a 2-high finishing stand containing the die-roll. This die-roll has a zigzag grooving tongue which inclines to and fro with respect to the edges of the working face of the roll. In one part it is broadly bevelled so as

* *Industries*, vol. xiii. p. 300.

† *Iron Age*, vol. I. p. 99, one illustration.

‡ *Ibid.*, vol. xlix. pp. 455-456, four illustrations.

to produce a broad bevel on the blank at the inner side of the heel ends, this grooving tongue also so dividing the blanks of one series in a bar from those of the other that a slitting machine can readily separate them. The die-roll has also two series of rail-scores arranged in pairs in such a manner that the pairs in one series alternate with those of the other series. Finally, there are heel-marking studs.

The product of rolling in the die-roll is a double blank bar, consisting of a series of alternating blanks. These blanks can readily be divided and bent into shape. The various other roll-trains are used for shoes of different shapes.

The blanks are heated in small coal-fired furnaces; the heated blank is bent to shape and is then transferred to the hammer, which consists of five or six rolls 4 inches in diameter, mounted on a revolving shaft. These strike a drawing blow upon the shoe-blank, drawing the metal towards the heel of the shoe. The punching-room contains forty-four machines, the burr left after the punching being removed by a machine of special design.

Cast-Steel Locomotive Wheels.—Cast-steel wheels have been in use in England for locomotives for some years past. The advantages presented by the substitution of cast steel for forged metal are the great lightness, the economy of manufacture, and the possibility of giving the pieces certain forms incompatible with the employment of forged metal. Professor A. Lepreux* gives details of the conditions of the manufacture and resistance of these wheels, and of the tests to which they are submitted for the London and South-Western Railway. His paper concludes with a description of four types of locomotives employed by this company, and an enumeration of the parts that are made of cast steel.

Rails.—A description is given by Mr. J. E. Watkins† of the development of the American rail and permanent way as illustrated by the collection in the United States National Museum. This paper, which forms a most interesting history of the subject, is illustrated by numerous sections of rails that have been used at various times both in America and in other countries. A short account is given of the early tramroads, and the simple bar sections that were used as rails, then the earlier thick rectangular, T, and pear-shaped sections are described.

* *Annales des Mines*, 9th series, vol. i. pp. 539-547, with six drawings.

† Report of the United States National Museum, Smithsonian Institution.

The invention of the flanged rail by Mr. R. L. Stevens, and the difficulties at first met with in its manufacture, are dealt with. Compound rails of various sections were employed on some lines, and are illustrated, as is also the Barlow rail. The rails of the intermediate and more recent periods are then discussed.

A dimensioned sketch* is given of the 100-lb. rail which is being laid by the Pennsylvania Railroad Company on parts of their lines. It contains a large amount of metal in its head, namely, 49 per cent., while 18·5 are in the web and 32·5 in the flange. The carbon contents are 0·55 per cent.

Steel Sleepers.—Steel sleepers of the "inseparable clip" type are dealt with by Mr. H. K. Bamber,† who gives particulars of the quality of the steel used and the methods of manufacture. Illustrations are given of the standard sleepers used on the Indian State, Mexican, and other railways, of the sleepers experimentally put down on the North Eastern Railway, and of other types. The specified requirements of sleeper steel at present are:—

1. That it shall be as even as possible in quality.
2. That it shall withstand an ultimate tensile stress of at most from 26 to 31 tons per square inch.
3. That it shall elongate at least 20 per cent. in a length of 10 inches.
4. That it shall show a contraction of area at point of fracture of not less than 40 per cent.
5. That it shall be capable of being bent double on itself to an inside radius of one-half its mean thickness without sign of crack or fracture.

The steel used is made by the Bessemer, basic, and open-hearth processes, these materials possessing the qualities of homogeneity, malleability, and ductility. The first of these qualities depends largely on the proper mixing of the steel, which is effected either by a mechanical mixer or by repouring the metal. Want of regularity in composition is apparently a great cause of failure in manufacture.

The analyses of the class of steel used by the five chief sleeper makers in the kingdom, and the results of tensile tests showing the quality and range of each, are given on the following page:—

* *Engineering News*, vol. xxviii. p. 56.

† *Minutes of Proceedings of the Institution of Civil Engineers*, vol. cviii. pp. 333-357.

Process of Manufacture.	1. Acid.	2. Acid.	3. Acid.	4. Basic.	5. Basic.
Carbon	0.13	0.12	0.12	0.09	0.11
Silicon	0.03	0.01	0.02	n)	0.02
Sulphur	0.06	0.06	0.05	0.05	0.05
Phosphorus	0.06	0.06	0.05	0.06	0.05
Manganese	0.40	0.40	0.70	0.42	0.75
Load per square inch, tons	30.41	27.38	27.31	28.30	29.90
Elongation, per cent. in 10 ins.	23.00	26.50	21.56	24.50	23.00
Contraction, per cent.	45.00	56.00	not taken	not taken	48.00

A number of analyses and tests of sleepers which broke on falling are given to show that a tensile strength of over 31 tons per square inch is not advisable. The following composition and strength is recommended for a standard sleeper steel:—

Carbon, per cent.	0.12
Silicon, per cent.	0.02
Sulphur, per cent.	0.05
Phosphorus, per cent.	0.05
Manganese, per cent.	0.70
Tensile strength, tons per square inch	28.00
Elongation, per cent. in 10 inches	24.00
Contraction, per cent.	50.00

When the mill can keep pace with the manufacture of the steel it is preferable to roll the ingots direct, thereby saving fuel and obviating the defects due to reheating. There are two methods of rolling steel sleeper plates: 1. Into the form of flat plates. 2. Into the form of trough-shaped plates. In the first case, for sleeper plates $13\frac{1}{2}$ inches wide, the section of ingots at about half their length measures 10 inches by 17 inches; while in the second case, the section at the same point is 15 inches square. In either case the weight of the ingot varies from 20 to 30 cwt.

As soft steel during rolling does not spread transversely, sufficient width must be allowed to form the edges. To secure sound edges the ingot is cogged down to $2\frac{1}{2}$ by 17 inches, and passed through an edging groove measuring $2\frac{1}{2}$ by 14 inches when making flat plates. Compression is also used when making trough sections. In rolling these sections the same moulds and cogging-rolls may be used as for making rails. In connection with the ingots, the points to be observed are that the mould is clean, and is closed as soon as possible. When the ingot is cogged down the crop ends are cut off, and it is sheared into slabs, which are "wash heated" as uniformly as possible. For rolling flat plates the slabs are reduced in four passes to $13\frac{1}{2}$ inches by $\frac{1}{2}$ inch by

120 feet long, and then sent through a finishing pass. "Boxed" rolls or rolls with collars and grooves to prevent side play cannot be used in rolling trough sections, so that they vary both in weight and thickness more than flat plates, and subsequent shaping is thus more difficult.

Steel sleeper plates, both of flat and trough section, are shaped while red-hot under a hydraulic or steam press, to which are attached suitably shaped cast-iron moulds. The sleeper plate having been placed in position on the bottom block, which is shaped to form the underside of the sleeper, the top table, and with it the upper block, is lowered, pressing the plate on to and folding it round the bottom block. Besides shaping the sleeper, these blocks, whose wearing surfaces are chilled, give to those portions of the plate which ultimately form the rail seats an inclination of 1 in 20.

The construction of the press is discussed, and the author is of opinion that the use of flat plates sheared instead of sawn to length is desirable. The most important operation is that of punching the clips or rail fastenings, as the life of the sleeper depends on their strength, and their gauge must be exact. As the sleepers are of irregular shapes, they would be distorted by annealing after punching cold, so this operation has to be done at a good red heat. Some experiments that are given show very clearly the danger of punching if the plate is allowed to become too cold.

Given the proper temperature, there are two methods of forming the rail fastenings in a sleeper, each having its advantages. In the first or direct method the clips are punched at once to their proper position, while in the second they are punched deeper, and are afterward brought back to their proper position by being hammered on to suitably shaped pieces of metal called drifts. The first is far the cheaper method, but the second gives the most uniform and satisfactory results, both as regards strength and finish.

The methods employed for punching the clips true to gauge are then described, the coatings are mentioned, and suggestions on the points brought forward are made.

Analysis of Russian Tire Steel.—Sergius Kern gives the following analysis of Russian crucible tire steel, partly made from Holtzer projectile scrap :—

C.	Mn.	Si.	S.	P.	Cr.
0.45	0.18	0.20	0.02	0.03	0.26

A sample tire made of this metal withstood forty blows of a 600 lb.

monkey without cracking, and was bent in the end into the form of the figure 8.*

Recent Progress in Gun Manufacture.—Mr. W. H. Jaques† describes the recent progress and the development which has been made in the manufacture of guns in the United States. The great feature has been the decrease in the number of the component parts of a large piece of ordnance. The author considers the built-up forged steel gun as the best. Open-hearth metal and crucible steel are the only ones suitable for gun construction. Authorities differ, he adds, as to the value of oil hardening, but they universally agree as to the benefits of annealing, but both are necessary to secure a reliable uniform product. Gas-heating furnaces are those best adapted for annealing cannon. The questions of shrinkage and of internal stresses are also considered. As to the erosion of the bore by the products of the combustion of the powder, this difficulty will probably be best surmounted by using a higher carbon steel for the bore, highly polished or hardened by mechanical mandrelling in order to secure the degree of smoothness requisite to prevent erosion by the powder products.

There are two main systems of breech construction in use: one the American-French interrupted screw, and the other known as the Krupp wedge. Hundreds of devices have been proposed for closing and gas checking breech-loading ordnance, but the most effective at the present time are the Canet-Whitworth breech mechanism and the De Bange gas check. The author enters into the question of gun construction at some length.

With regard to the materials employed in the construction of cannon, steel, advocated as early as 1860 by Whitworth, is the one that has finally been adopted. For the steel barrel, Armstrong substituted in 1861 a wrought-iron coil. Such a coil ought never to have been employed. Breech-loaders, too, were abandoned in England, and muzzle-loaders again employed, this coil being still employed—a grave step of retrogression. Whitworth and Krupp, however, continued to manufacture steel breech-loaders. In the United States the cannon made are almost exclusively of fluid-compressed, hydraulic-forged steel, and such castings are now made of large size. Thus the 8-inch gun in 1887 had ten parts; now it has but three. One of the greatest faults of the British 110-ton guns is that they consist of too many pieces, the

* *Chemical News*, vol. lxx., p. 290.

† Paper read before the United States Naval Reserve Association; *Iron Age*, vol. xlix., pp. 1166-1167.

chase hoops in particular being too numerous and short to be of any use in supplying the longitudinal support which a tube of such length requires. On the other hand, Whitworth's new 35-calibre 12-inch 50-ton breech-loaders are composed of three pieces only.

With regard to the other materials and systems of gun construction which have been proposed of recent years, the author mentions the Woodbridge wire-wound guns of 10-inch calibre, employing longitudinal bars and soldered wire; the Crozier 10-inch wire-wound guns, jacketed and hooped with steel castings; the Haskell multi-charge gun, and various cast iron and direct Bessemer cast guns and mortars. The use of an addition of 3 per cent. of nickel to the steel, the author observes, would probably mean that the pressure limit might reach 20 tons, as compared with the safety limit of 15 tons in the case of guns consisting of ordinary steel.

The Midvale Steel Company of Philadelphia is erecting a casting-plant which will include two 25-ton open hearths, and an oil-tempering plant capable of dealing with guns of the largest size. An armour-plate mill is also to be erected. A new machine-shop for gun work is of the dimensions 260 feet by 210 feet by 53 feet clear height. The Holtzer armour-piercing shells are manufactured by this company.*

A plan is published † of the new south wing of the Watervliet gun shops. This wing is 400 feet in length by 154 feet in width, and the plan shows the position of the various machines erected. These include 12-inch gun lathes and four 16-inch gun lathes. In addition there are two 12-inch and one 16-inch jacket lathe, one 12-inch rifling machine, one 12-inch and one 16-inch threading and slotting machine; three 48-inch, four 60-inch, one 72-inch, and one 78-inch lathe; two 72-inch boring mills, and three planers, 36, 48, and 72 inches; a 72-inch radial drill, a 26-inch slotter, and a 66-inch horizontal borer, besides a number of smaller lathes, shapers, slotters, &c. The whole is served by two 30-ton cranes, one of 60 tons, and another of 120 tons.

Mr. R. A. Robertson ‡ has devised an arrangement for casting cannon. Water is forced through a pipe inserted in a hollow core extending entirely through and beyond the ends of the casting. The core with its pipe is withdrawn as soon as the molten metal has set, and water is then forced through another pipe inserted in the cavity of the casting made by withdrawing the core. This pipe extends through

* *Iron Age*, vol. xlix. p. 990.

† *Ibid.*, vol. l. p. 104.

‡ *Ibid.*, vol. xlix. p. 1263, four illustrations.

the cavity, its outlet being below the body of the casting. In flowing back to its outlet, the water touches the surface of the bore at every part, cooling the casting more rapidly than would be possible if contact with the core were retained. While the casting is being cooled, radiation of heat from its exterior is retarded by fires kindled in the moulding-pit. The operation of casting the cannon is described and compared with the older method.

The Harvey Process.—A plant for the treatment of steel armour-plates by this process is to be built at the Aboukoff Armour Works, ten miles from St. Petersburg. This plant is being erected in connection with a contract recently made with the Russian Government for the treatment of armour-plates for the Russian fleet.*

Large Armour-Plate Saw.—In April last there was erected at the Homestead Steelworks, Pennsylvania, a large steel saw of German manufacture, weighing 110 tons, to be used in cutting nickel steel armour-plate. These armour-plates range in weight from 8 to 38 tons, and reach a length of 20 feet and a thickness of 20 inches. The saw has a blade $7\frac{1}{2}$ feet in diameter geared above and revolving horizontally. The armour-plate is placed on a tilting-table, which is adjustable to any angle, and presented to the edge of the saw endwise. The cost of this saw is stated to have been £7000.†

The Manufacture of Projectiles.—A description is published‡ of the method in use by the United States Projectile Company for the manufacture of shells and shrapnel for the United States Government. These projectiles vary from 4 inches to 6 inches in diameter. The billet, which is slightly larger in diameter than the finished product, is heated and then converted by a press into a very blunt-shaped cone. It is then placed under a cupping-punch, this forming a shallow recess in the top. The blank is then forced through a ring by the plunger of a larger press, being thus converted into a cylinder. It is next forced successively through a series of rings of different sizes, each a little smaller than the other, until the desired diameter has been reached, when it is passed through a straightening sleeve. It is then in shrapnel form, but if it is desired to convert it into a shell, the open end must be closed in. To effect this, the end is heated for a

* *Iron Age*, vol. xlix. p. 657.

† *Ibid.*, p. 780.

‡ *Ibid.*, pp. 1032-1033, with plate.

length of about 5 inches, the base of the shell is placed in water, and the heated end closed by bringing down on it the conical die of a small press. The shell so produced is taken to a drop hammer, inverted, and placed in a conical die, from the centre of which projects a punch fitting within the opening in the apex of the shell. A few blows of the hammer suffice to bring the conical end of the shell into perfect shape. The 5-inch forged shell measures 16.85 inches in length, with an admissible error of 0.15 inch; its outside diameter is 4.97 inches, with an error of 0.01 inch. The side walls are 0.35 inch thick and the base 1 inch, the permissible errors being 0.03 and 0.05 inch respectively. The presses which are used in the manufacture of these shells are described, as also is the method of gauging and testing the shell. The steel must have a minimum tensile strength of 70,000 lbs. per square inch. Some of the straightening sleeves used have withstood the passage of 400 or 500 shells, the average being between 200 and 400. This is stated to be a much better result than that usually obtained elsewhere.

The manufacture of forged steel projectiles, especially of common and shrapnel shell, is described by Mr. D. Carnegie.* Armour-piercing projectiles are made by drawing down a cast-steel ingot by swages under a steam-hammer. Other methods have been tried, but without much success. The common and shrapnel shell are thinner in the body. They have been made by solid drawing from a blank, but the more successful plan is to weld wrought-iron bases into tubular steel. A very efficient process is to press the shells out of short steel cylinders. The usual process is to cut bars of round steel into the requisite lengths, heat the blanks, and indent one end in a press. The block is then reheated, cleaned from scale, and again put through a hydraulic press, which forms it into the shell. One machine in use cleans the ingot automatically and guides it into the press. The pressure required necessitates the use of steel punches of the best quality, while the best material for the dies is found to be hard cast iron. Details and illustrations of the machines employed are given, with a diagram of the work done in the process of manufacture.

Electric-Welded Projectiles.—The manufacture of electric-welded projectiles in the United States is described by Mr. H. P. Maxim.† Steel blooms cast hollow are rolled into a thick-walled tube having

* *Minutes of Proceedings of the Institution of Civil Engineers*, vol. cx. pp. 333-342.

† *Proceedings of the United States Naval Institute*, vol. xviii. pp. 251-257.

the approximate dimensions of the body of the shell. The tube is cut into short lengths, and the head and base of the projectile, which have been formed in dies, are then welded on in an electric-welding machine. After this it is machined to the requisite size, and is then hardened. This shell is efficient against armour of moderate thickness and is cheap. Armour-piercing projectiles are manufactured in two parts, the head section is first hardened uniformly all over, and its point is placed in water during the welding process, so that the temper is drawn evenly to the point. Shrapnel shell is also manufactured by electric welding, the diaphragm is put in while the weld is hot, and the metal slightly swaged to secure it. Up to the present the largest shells manufactured are 6 inches in diameter and weigh empty 94 lbs. A short description of the two forms of the welding machines employed is also given.

A Sheet-Iron Gauge.—A bill has been introduced in the United States Congress, under which the manufacture of plates and sheets, according to the standard adopted, is to be compulsory. In the standard proposed there are forty-three numbers, the weight per square foot varying from 20 lbs. to 0.7 lb., and the corresponding thickness from 0.5 inch to 0.00425 inch.*

Tin-Plate Manufacture in America.—A new tin-plate factory has been erected at Elwood, in Indiana. Illustrations of the plant are given.† Bessemer steel bars are used, and all the furnaces and annealing ovens are heated by natural gas. The present output is stated to be 1200 boxes per week, over 200 hands being employed.

A number of illustrations are published‡ of the tin-plate works belonging to the St. Louis Stamping Company, United States. The plant comprises a sheet-mill house 150 feet long by 100 wide, an annealing department 150 by 65 feet, and a tinning shop 250 by 60 feet. In another portion of the works the billets and bars used are rolled to No. 16 gauge, then doubled, re-rolled three times, and sheared to the different sizes. The doubler and shearer is of special design. An upright bar, jointed at its base, has two arms, one forming the doubler and the other the shearer, working alternately by the movement of a cam at the top. There are four mills in the sheet-mill

* *Iron Age*, vol. xlix. p. 765.

† *Industries*, vol. xiii. p. 444.

‡ *Iron Age*, vol. xlix. pp. 909-912, nine illustrations.

department, each mill consisting of a roughing and a finishing roll. The agitator has a capacity of 500 boxes of tin-plates a day.

At the Somerton Tin-Plate Works, Brooklyn, the main mill consists of six sheet-mills and a train of three sets of cold rolls, the latter placed one behind the other so that the cold rolling can be made continuous and automatic. The six sheet-mills are arranged in three groups, driven by gearing from the main shaft. On the same shaft are eccentrics which drive the squaring and doubling shears, in close proximity to which is a shoot leading to a lower floor, through which the sheer scrap is delivered, where it is bundled by hydraulic pressure. Each mill is served by a heating furnace, of special design, to reduce oxidation to a minimum, the fuel used being crude oil. Oil is exclusively employed in this mill, provision being made to pump the oil from iron tank boats on an adjacent canal. The whole line of the heating furnaces is commanded by an overhead track, by which the steel is distributed. The line of rolls is commanded by an overhead trolley, so that the rolls can be readily conveyed to a special grinding machine to turn the rolls whenever necessary. Behind the train of rolls a large annealing furnace is being erected. Special machinery will also be put in for opening the packs. The cold rolling plant is to be supplemented by an automatic sorting machine to reject all sheets which are not within the range of specifications as to gauge. In the middle of the mill is a tandem compound Corliss engine.*

Coating Steel with Copper.—A method of coating steel with copper appears to have found a certain amount of success. It consists in casting a short copper ingot on a core of iron or steel, the copper being shorter than the core, and being thicker at one end than at the other, so as to compensate for the unequal expansion of the two metals during rolling. The compound ingot after the first pass is allowed to cool slightly, so as to chill the copper in order to reduce its ductility to that of the core. The process was first used for wire, but has also been adopted for sheets and plates.†

Rust-Proof Coating for Iron.—Mr. C. Platt ‡ gives the results of several experiments he has made to produce a rust-proof coating on iron with the aid of acids. The most successful procedure was to expose coils of wire to the action of steam mingled with small propor-

* *Iron Age*, vol. xlix. p. 454.

† *The Engineer*, vol. lxxiii. p. 536.

‡ *Engineering and Mining Journal*, vol. liv. p. 78.

tions of acid vapour. After a few hours' exposure there is a fine brown closely adherent coating. The wire is then heated for an hour in an oven at a temperature of 100° to 125° C., and afterwards dipped in an oil bath. Superfluous oil is removed by a centrifugal machine, and the wire is again heated. A closely adhering film of oxide is thus produced, and the process is being used on a commercial scale.

A method, proposed by Mr. J. Forbes* for producing a rust-proof coating on iron, consists in packing the articles to be coated in a box in some material which will not give off oxygen, mixed with some such substance as black oxide of manganese. A satisfactory result has been obtained.

Coating Iron with Tar.—Raw tar is not adapted for use in coating iron. The coating produced rapidly scales away and destroys the metal, the action being due to the carbolic acid which is present in the tar. If this tar, however, is heated with 2 or 3 per cent. of lime to neutralise the acid, it may afterwards be used without injury to the iron, and at the same time give a satisfactory coating to the metal.†

Protecting Iron-Work in Tunnels from Corrosion.—In a railway tunnel, where the roof was supported by wrought-iron girders, considerable corrosion occurred in the iron-work owing to the gases from the engines. The method adopted to prevent this is described by Mr. J. G. Dagrón.‡ It consisted in painting the girders with asphalt paint and sealing them in with a flat arch of firebrick tiles with cement mortar on the underside.

* *Proceedings and Transactions of the Nova Scotian Institute of Science*, vol. i, pp. 27-30.

† *Bayerisches Industrie und Gewerbe Blatt*, 1892, p. 334.

‡ *Transactions of the American Society of Civil Engineers*, vol. xxvii, pp. 324-330, with illustrations.

PHYSICAL PROPERTIES.

The Molecular Changes in Iron.—M. Moreillon* gives the results of a series of experiments made with a view to elucidate the molecular changes which iron may experience when submitted to physical or more purely mechanical treatment. The material experimented with was puddled iron, sodium carbonate having been used as an addition during its manufacture. The author shows by illustrations the modification in the texture of the metal which results from simple heating, then that produced by mechanical treatment (hammering) and by drawing down, and also the influence which annealing exerts on the bar so reduced in dimensions. He arrives at the conclusion that mechanical treatment modifies the texture of iron, destroying fibrous structure and replacing it by a granular one. Hammering in addition destroys the homogeneity of the bars. Annealing at a low temperature destroys the effects produced by drawing down the metal, and even those due to its having been heated at too high a temperature. By the conversion of the fibrous iron into the granular metal the resistance to rupture is diminished; the elastic limit, on the other hand, is but little changed. It is even slightly higher in the iron with granular structure than in the fibrous metal. The elongation becomes less, and generally the metal which has experienced this change of structure is weakened. The presence of carbon tends to diminish the size of the grain, while silicon when present in quantities not exceeding 0.15 per cent. has no apparent influence. Phosphorus exerts a marked augmenting action on the size of the grain. Sulphur and manganese have little or no action on this property of iron.

The Cellular Theory of Steel.—L. Baclé† criticises the theory of Osmond and Woerth as to the effect on its physical properties of the cellular structure of steel. The author discusses the variations in the fracture of steel. Thus in unhardened steel a mass of iron carbide encloses nodules of more or less pure iron. These nodules, each

* *Bulletin de la Société Industrielle de Mulhouse*, vol. lxi. pp. 629-656; *Génie Civil*, vol. xxi. p. 305.

† *Génie Civil*, vol. xxi. pp. 71-74, 198-202.

1892.—ii.

surrounded with a protecting envelope of iron carbide, are the elementary or constructive cellules. A combination of such cellules forming a composite cell is the "grain" of the metal. The carbon exists in at least two distinct forms, that combined with the iron which exists in relatively large percentage in annealed metal, where it forms the binding material, and the hardening carbon of hardened steel. The former is insoluble in dilute nitric acid in the cold while the latter dissolves, the two forms corresponding respectively with the carbon of the iron carbide obtained from the decomposition of ferrocyanide, and the other with that produced from sugar at a moderate temperature. As is well known the iron undergoes similar changes. Osmond and Wörth consider that iron carbide dissociates normally at high temperatures. At a given temperature a portion corresponding to that temperature has been so dissociated, whilst a portion remains unchanged. A sudden plunge into water causes the carbon to remain in the suddenly cooled metal in the same form as that in which it existed at the temperature from which the metal was cooled. The author proceeds to quote at length from the memoir of Messrs. Osmond and Wörth, and to discuss generally the well-known work of the former writer as to the changes which take place in steel when it is slowly cooled from a high temperature.

The Passive State of Iron and Steel. — The third and concluding part of Mr. T. Andrews' * researches on the passive state of iron and steel deals with the relative passivity of wrought iron and various steel bars, and the influence of chemical composition and of physical structure on their passive state, and with the relative passivity of wrought iron and various steel plates in cold nitric acid. Full analyses of the various plates used are given, with the results of a large number of experiments. The rods were treated in their original rolled state and after drawing. Generally the wrought iron in both these series of experiments was electro-positive to the steels, showing that it was less passive. After drawing, the wrought iron did not always assume the electro-positive position until after some hours' immersion in the acid, but then the electro-motive force increased, showing that it gradually became less passive than the steels. In the case of soft Bessemer and soft open-hearth steels there were similar interchanges, which are not easily accounted for. Wrought iron was found to be permanently more passive than tungsten steel. Hard steels, containing more combined carbon, are more passive than mild steels, thus showing the effect of

* *Proceedings of the Royal Society*, vol. xlix. pp. 481-488.

carbon. The author's previous investigations * on this subject are summarised in the concluding remarks.

The Viscosity of Steel.—The treatise on the viscosity of solids, by Mr. C. Barus,† is a contribution towards the solution of problems bearing on the viscosity of rock masses. The experimental investigation of the viscosity of steel leads the author to believe that he has discovered a trustworthy working hypothesis substantially corroborative of Maxwell's theory on the subject.

The Changes in Ingot Metal.—A. Sattmann ‡ describes a long series of experiments made with a view of showing the influence of physical causes in effecting changes in the properties of ingot metal. The metal submitted by the author to examination was from the open-hearth furnaces of the Donawitz Works. A portion was acid-made metal, while the remainder was produced by the basic process. The former contained 0·19 per cent. of carbon, had a tensile strength of 26 tons per square inch, 24·5 per cent. elongation, and 59 per cent. reduction of area. The basic ingot metal contained 0·15 per cent. of carbon, had a tensile strength of 22·8 tons per square inch, an elongation of 28·5 per cent., and a reduction of area of 65 per cent. The elongation was measured on a length of 7·87 inches.

The first experiments were made to ascertain the effect of mechanical treatment exerted at different temperatures, the specimens being reduced by a rapid-striking hammer from a thickness of 0·39 inch to one of 0·35 inch. The following were the results obtained after treatment at the temperatures mentioned :—

Temperature, Degrees C.	Acid Metal.			Basic Metal.		
	Tensile Strength, Tons per Sq. Inch.	Elongation, per Cent.	Reduction of Area, per Cent.	Tensile Strength, Tons per Sq. Inch.	Elongation, per Cent.	Reduction of Area, per Cent.
-19	26·3	15	59·8	25·2	19·5	64·0
+10	31·3	7	55·7	28·3	7·5	64·6
40	31·5	7	50·6	30·4	7	55·5
200	37·0	4	37·8	30·7	7	57·2
320	37·5	4	47·2	30·7	7	56·7
600	27·6	12	56·0	27·2	10	56·0
800	27·0	16	56·2	25·6	21·5	64·7
1000	26·9	22·5	64·5	24·1	22	67·6
1100	26·2	22·5	62·5	23·3	21	67·3
1300	26·3	18·5	61·0	22·9	19·5	68·9

* *Journal of the Iron and Steel Institute*, 1890. No. II., p. 848; 1891. No. I., p. 426.

† *United States Geological Survey, Bulletin*, No. 73, pp. 1-139, with six plates and twenty-eight figures in the text.

‡ *Stahl und Eisen*, vol. xii. pp. 550-558.

With regard to the bending tests, the acid metal, hammered at a temperature of 200° C., could be bent double when cold, but showed small cracks at the bend. That hammered at a blue heat, 320° C., broke at an angle of 20°. The basic specimens hammered at these temperatures could be bent completely, but showed slight cracks. All the other specimens could be bent completely double without showing any signs of cracks. It is interesting to observe that those specimen bars, which were submitted to the influence of the temperature of -19° for some time, showed a lower tensile strength but a much greater elongation and reduction of area than the bars treated at slightly higher temperatures. The best temperature for the mechanical treatment of ingot metal would appear to be a bright red.

In the next series of experiments the influence of annealing on the hammered bars was examined. The bars, which had been treated at a bright white heat, became much softer and more ductile by this treatment; but those treated at somewhat lower temperatures were not softened to so considerable an extent. With a view to ascertain the influence which the simple heating of a piece of metal exerts on its physical properties, a number of test-pieces were heated to various temperatures and then allowed to cool slowly in the air. The results obtained were as follows:—

Temperature, Degrees C.	Acid Metal.			Basic Metal.		
	Tensile, Tons per Sq. Inch.	Elongation, per Cent.	Reduction of Area, per Cent.	Tensile, Tons per Sq. Inch.	Elongation, per Cent.	Reduction of Area, per Cent.
200	25.4	27	64.7	22.7	30.0	69.3
320	26.2	24	62.4	22.9	28.5	68.5
600	26.0	26	61.1	23.3	29.0	69.4
800	26.0	24	64.1	22.8	31.0	68.2
1000	26.4	24	65.1	23.1	29.0	71.6
1100	27.2	24	64.9	22.7	33.0	71.8
1300	25.7	22	63.9	22.4	30.0	73.0
Not heated	26.0	24.5	59.0	22.8	28.5	66.0
Tested at } - 19 }	25.8	19.0	63.9	23.1	26.5	80.8

These results show that heating the material to a yellow or a blue heat has no influence on the properties of the cooled-down bar. Heating to a white heat affects the quality of the acid metal, but does not appear to have much influence on the basic metal.

Other bars were heated to various temperatures and cooled slowly under a covering of ashes, whilst others again were heated, cooled

rapidly, again heated, and then allowed to cool slowly under a covering of ashes. In the first case the acid metal was softened and improved in each case, whilst the basic material, heated to a blue or a yellow heat, gave less favourable results than did the original metal. In the second case both acid and basic metal was greatly improved. When heated to various temperatures, and then plunged into water of a temperature of 6° C., the results were as follows:—

Temperature, Degrees C.	Acid Material.			Basic Material.		
	Tensile Strength, Tons per Sq. Inch.	Elongation, per Cent.	Reduction of Area, per Cent.	Tensile Strength, Tons per Sq. Inch.	Elongation, per Cent.	Reduction of Area, per Cent.
200	24.3	22.5	65.3	23.9	26.0	65.5
320	24.2	24.6	65.6	23.6	28.0	69.4
600	26.5	16.0	62.7	24.9	22.0	67.3
800	36.4	13.0	54.8	38.3	14.5	56.6
1000	31.3	20.0	66.6	29.3	15.0	69.1
1100	32.2	20.0	61.1	29.6	15.0	63.6
1300	39.8	10.0	43.6	30.7	12.0	65.6

It will be observed that in both metals the experiments show a first maximum tensile strength at 800°, followed by a drop and then by a further increase.* The basic steel heated to a blue heat gave much better results on testing than did the acid metal. In a further series of experiments bars similarly hardened were afterwards carefully annealed and then re-examined in the testing-machine. With the exception of the bars heated to a white heat, annealing softened the metal completely. Those heated to the temperature of 1300° still remained hard even after this annealing.

The Microscopic Examination of Iron.—Professor A. Martens† publishes the results of a further series of microscopic examinations relating to wires. He recommends that, in addition to tensile tests, bending tests should be made in the following manner: The wire is fixed tightly in the jaws of a press, and then bent back sharply over the slightly rounded jaw, the lever used for causing this bending requiring to be placed right against the surface of the wire. After the removal of the force the wire, bent back to 90°, may

* Some high carbon steels which were examined in the metallurgical laboratory of the Royal College of Science showed a similar maximum at a little above 800°, followed by a minimum at a temperature slightly above 900°.

† *Mittheilungen aus den Königlichen Technischen Versuchsanstalten*, Part 2; *Stahl und Eisen*, vol. xii. p. 672.

spring back, the angle so shown giving a measure of the elasticity of the wire. A number of illustrations of the fractures are given. Regarding unexplained fractures of steel wires the author has bent a number of such wires over an edge of 0.2-inch radius, and even when only slightly bent the wires showed a great tendency to break, the fracture being always very marked and peculiar. One end of the fractured wire shows a conical depression and the other a corresponding cone, the point of which was always in the same direction. To ascertain the cause of this, the author instituted an examination of the surfaces of wires filed down longitudinally to one-half their thickness. The polished surfaces so produced were etched with strongly diluted acid, and microscopic examination then showed that even the straight unbent wires gave evidence of the presence of numerous small conical-shaped portions. In the bent portions there showed themselves in the centre of the wire a large number of cracks across the wire, and distant from each other about one-fourth the wire thickness. One section shows the central portion of the wire completely separated from the outer jacket. The author attributes these points which he has observed to the following causes. When the wire is drawn the material of which the outer jacket is composed is shifted somewhat in position as regards that of which the core is composed. If the material is of a homogeneous character, then from the surface of the wire to the core the material shifts its position regularly and concentrically; but when the material is irregular in character, then the stretching powers of the different portions being unequal a number of radial cracks are formed between the various layers, and these cracks follow each other at distances which depend on the relative degrees of adhesion existing between the various layers, and on the relative degrees of tenacity of the various parts.

Mr. P. Kreuzpointner * publishes twenty-one illustrations showing the microscopical structure of various varieties of iron and steel. He gives a historical sketch of the work that has been done on this subject, referring especially to that of Martens, Sorby, Garrison, and Wedding. The illustrations published by the author are selections from a number described by Martens, and they illustrate not only flaws in castings, but also the structure of the sound portions of the metal. These the author discusses, observing that his experience has shown him how important is the use of the microscope when it is a question of examining and testing large masses of metal.

* *Iron Age*, vol. xlix. pp. 1224-1225.

The Influence of Extreme Cold on Ingot Iron.—The results published by Professor Steiner* induced Messrs. Köpke and Harteg† to publish the results of an investigation of this question made by them in connection with Professor Hempel. The material submitted to examination was in the form of flat bars 1·97-inch in diameter and 19·7 inches in length. The proportion of carbon in the metal was as follows: fourteen test-pieces of weld iron, 0·119 per cent. of carbon; fourteen of basic open-hearth metal, 0·152 per cent. of carbon; two of acid Bessemer steel, 0·363 per cent. of carbon; and two of similar steel, containing 0·735 per cent. of carbon. Solid carbonic acid was used as the cold-producing agent in conjunction with sulphuric ether, the temperature of the experiments being as a rule from -70° C. to -80° , and occasionally as low as -100° . In making the experiments there was in each case an insertion made in one end of the test-bar, the hollow so produced being filled with mercury. During the cooling process care was taken that after the mercury had solidified, a period of at least thirty minutes was allowed to elapse before the bar was submitted to test. The experiments were comparative, a cooled bar and a similar bar in its original condition at the ordinary temperature— 15° to 20° C.—being tested under similar conditions. Each bar was then submitted to the action of a falling weight of about 100 lbs. falling through a height of 35 inches. In the first experiments the bar was turned after the first blow, the second blow being directed on the bent side, the result being to straighten the bar. This operation was repeated until the mercury at the end of the bar began to melt. This occurred at the end of the eleventh blow, no fracture having taken place. In the later experiments the blows were so directed as to increase the bend with each blow. The cooled bars showed increased resistance as compared with the uncooled bars. In the various experiments the weld iron showed itself much more resisting than the ingot metal, the increased force required to produce a given bend in the cooled as compared with the uncooled bars being in the proportion of 1·47 : 1 in the case of the weld iron, and of 1·49 : 1 in that of the ingot iron. The ingot metal thus showed itself slightly more readily affected by the hardening influence of cold than weld iron. The Bessemer metal with 0·363 per cent. of carbon sustained without fracture six blows both in the original and in the cooled condition without fracture, but the higher

* *Journal of the Iron and Steel Institute*, 1892, No. I., p. 466.

† *Der Civilingenieur*, vol. xxxviii. pp. 207-214.

carbon steel, while withstanding this treatment in its uncooled condition, broke at the sixth blow after having been cooled. The fracture was fine-grained.

The table below shows the permanent deflection in inches for one blow with these two samples, the monkey in the first three experiments weighing about 152 lbs., and in the second three 240 lbs. In both cases the height of fall was $31\frac{1}{2}$ inches.

Carbon, per Cent.	Temperature, Degrees C.	Deflection in Inches.					
		Weight, 152 lbs.			Weight, 240 lbs.		
0.363	Over 53.6	0.31	0.28	0.213	0.417	0.323	0.327
...	Under -40	0.248	0.20	0.126	0.417	0.335	0.26
0.735	Over 53.6	0.165	0.146	0.094	0.217	0.173	0.165
...	Under -40	0.154	0.091	0.075	0.232	0.240	fracture

The Influence of Temperature on the Magnetisation of Iron.—With a view to reconcile the somewhat discordant results of previous investigators, Mr. H. Wilde * has conducted a number of experiments on the influence of temperature on the magnetisation of iron and other magnetic substances. The principal results show a continual diminution of the magnetic power of the iron from the lowest to the highest temperatures. At one point the magnetic power increases rapidly as the temperature falls, the temperatures being given by comparison with the lines of the spectrum. Even at the point of incipient fusion a measurable amount of force was found. In some previous experiments an increase of magnetic power with the temperature has been found, but the mass of iron, on which depend the time and limit of its magnetisation, does not appear to have been taken into account. That this factor has some effect is shown. Besides iron, nickel and cobalt were also experimented upon.

Magnetism in Iron.—Professor G. F. Fitzgerald † gives some calculations on the rate of propagation of magnetism in iron, in which he attempts to estimate the velocity of disturbance in a row of magnets arranged and reacting according to Ewing's theory of the structure of a magnet. Slow vibrations give a short wave-length instead of a long one, as might be imagined.

A treatise on magnetic induction in iron and other metals has been

* *Proceedings of the Royal Society*, vol. 1. pp. 109-118.

† Paper read before the British Association, August 1892.

published by Professor J. A. Ewing.* The methods for measuring the magnetic properties are dealt with, and results obtained with various metals are given. Magnetic hysteresis is discussed, together with the effect of weak and of strong currents. The influence of stress and temperature are dealt with, and the concluding chapter refers to the molecular theory of magnetic induction.

Mr. M. E. Thompson† discusses the magnetic permeability of special irons for electrical purposes. The greater the permeability the less is the weight needed in the construction of dynamos and motors. Cast iron, although its permeability is low, is usually employed, as it is so readily moulded into form, but wrought-iron castings have been used with some success. Some tests have recently been made with various samples of special irons at the Cornell University by a modification of the Rowland method, and the results of these tests are set out as curves. The advantage of steel castings over cast iron is clearly shown, and it is expected that the latter will speedily be replaced by the former. In the course of some discussion some further results were given describing the effect of aluminium and other materials.

Mr. S. Bidwell‡ describes some experiments made by him on the changes produced by magnetisation in the length of iron and other wires carrying electric currents. The results are plotted as curves, but no explanations of the results can be given until further experiments have been made. The results, however, show that in an iron wire carrying a current the maximum elongation is greater, and the retraction in strong fields is less, than when no current is passing. The effect of the current is opposite to that of tension.

Hardening Steel Magnets.—Experiments made by Dr. L. Holborn§ show the influence of hardening on permanent and induced magnetism. The main results of his researches are as follows: The permanent and induced magnetism of a hardened steel rod is dependent on the temperature at which it was hardened. The difference in the magnetism of rods, hardened at various temperatures, increases, other things being equal, with the proportion of carbon in the steel. The best magnet steel gives but moderately strong magnets if it is not hardened at the right temperature. Rods, 9 millimetres (0·35-inch)

* "Magnetic Induction in Iron and other Metals," pp. 370, with 159 illustrations. London.

† *Transactions of the American Institute of Electrical Engineers*, vol. ix. pp. 250-262.

‡ Paper read before the Royal Society, May 19, 1892; *Proceedings*, vol. li. pp. 495-503.

§ *Zeitschrift für Instrumentenkunde*, vol. xi. p. 113.

in diameter and 100 millimetres (3·94 inches) in length, were prepared from eight varieties of steel, analyses of which gave the following results:—

Steel.	C.	Si.	W.	Mn.	Ni + Co.	Cu.
Tungsten steel (Böhler Bros.)	1·05	0·38	2·80	0·34	trace	—
Tungsten steel (Seebohm & Dieckstahl)	1·14	0·40	2·16	0·24	—	—
Tungsten steel (Remy)	0·54	0·22	2·70	0·31	0·09	—
Tool steel (Söding & Halbach)	0·81	0·29	—	0·28	0·15	trace
Manganese steel (Söding & Halbach)	0·76	0·25	—	0·28	0·18	trace
Tool steel (Jonas & Colver)	0·93	0·16	—	trace	—	—
Tool steel (Marsh Bros. & Co.)	1·45	0·23	—	0·05	trace	—
Silver steel	1·08	0·13	—	0·28	0·10	—

Each of these rods was heated in an iron tube in a gas-furnace to the hardening temperature and cooled in water. The hardness of the rods was estimated from their specific electrical resistance, whilst the magnetism was determined with the aid of a Kohlrausch magnetometer. In the following table, t is the temperature of hardening, w the specific electrical resistance, R the permanent electric resistance, J the magnetism induced with 167 C.G.S. units, and J_1 that induced with 130 units.

Steel.	t .	w .	R .	J .	J_1 .
Styrian steel (Böhler Bros.)	745°	31·3	1332	4980	—
	850°	41·2	1734	4500	—
	1050°	43·1	1111	3920	—
English tungsten steel. (Seebohm & Dieckstahl)	745°	24·2	657	5350	—
	850°	40·3	1731	4790	—
	1050°	43·7	1081	3750	—
Westphalian tungsten steel. (Remy of Hagen)	765°	31·7	1505	—	5480
	920°	31·1	1484	—	5430
	1050°	34·0	1292	—	5210
Tool steel (Söding & Halbach)	855°	31·7	1491	—	5180
	910°	32·3	1461	—	5080
	1090°	30·6	1417	—	5030
Tool steel (Jonas & Colver)	855°	35·7	1410	—	4580
	910°	36·5	1384	—	4430
	1090°	34·5	1243	—	4500
Silver steel (Make unknown)	850°	35·6	1275	—	4300
	945°	39·8	1068	—	3580

Magnetic Properties of Aluminium Iron.—In a recent number of the *Cornell Crank* * Mr. C. Eickemeyer details the results of some investigations as to the magnetic properties of aluminium iron. Preliminary tests showed that these differed very little from those of

* Through the *Electrician*, vol. xxix. p. 475.

ordinary cast iron, so that carefully prepared test-pieces were made, and the method of using them is described. The addition of aluminium is thus shown to have but very slight effect on the magnetic properties of iron.

Electrical Resistance of Iron.—A number of experiments have been made by Professors J. Dewar and J. A. Fleming* on the electrical resistance of metals at temperatures down to the boiling-point of oxygen. Amongst the metals experimented upon are iron and nickel. In the case of iron, not only does the resistance decrease largely with the decrease in temperature, but the rate of change increases as the temperature increases. In the case of nickel, the presence of impurities has considerable effect, as it lessens the increase of conductivity on cooling. At ordinary temperatures, pure iron has a specific resistance about seven times that of pure copper, but at -182° C. it is only two-thirds that of copper at the ordinary temperature. The investigations seem to show that at absolute zero, the resistance would be either null or exceedingly small.

The Methods of Testing Steel.—A preliminary progress report has been issued by a committee appointed by the American Society of Civil Engineers† to report on uniform methods of testing materials used in metallic structures, and on the requirements for these materials to further improve the grade of such structures. In answer to a circular letter, a number of answers have been received, and these deal with the shape and size of the test-pieces and the methods of tests to be employed in testing cast iron, wrought iron, and steel.

Testing Machines.—An "extensometer," or device for measuring the stretching or shortening of test-pieces, devised by Professor J. B. Johnson,‡ is described by him. Two collars are held on the specimen by set-screws, and each carries a 4-inch graduated circle and vernier needle. A steel rod attached to each collar bears on a spindle on the other collar and moves it frictionally. These rods are placed on opposite sides of the test-piece, so that bending is allowed for by taking the average of the readings. The results of a test with this device are given.

* *Philosophical Magazine*, vol. xxxiv, pp. 326-337.

† *Proceedings*, vol. xviii, pp. 61-71.

‡ *Engineering News*, vol. xxviii, pp. 114-115.

Cast-Iron Test-Bars.—Mr. Bagshaw * draws attention to the fact that cast-iron test-bars give better results when tested with the thin edge in tension, and gives as explanation the fact that in casting the impurities rise to the top or thick side. Mr. E. R. Verity and Mr. A. Binns † give the results of some tests on these points. Bars 2 inches by 1 inch in section, broken on a span of 3 feet, had a mean breaking-load of 3267 lbs. with the thin edge in tension, and 2704 lbs. with the thick edge in tension. The broken halves were again tested, giving 7258 lbs. and 5808 lbs. respectively. Three of the quarter bars were then slit down the centre, turned up, and tested in tension. Those from the thin edge had an average breaking-load of 13·55 tons per square inch, and from the thick side of 12·90 tons. Mr. J. D. Mackimson points out that the flawed metal would be removed on turning the bars from the thick side, and the experiments are also commented upon by Mr. R. H. Cabena.

Malleable Cast Iron.—Experiments have been conducted by the Admiralty at Sebastopol, Russia, on the strength of malleable cast iron, made at the Sestoretzk Ironworks. The bars had a section of 1·53 by 0·3 inches, and broke at a tensile strength of 21·1 tons per square inch, with an elongation of 0·125 inch. One bar was folded several times hot, and only cracked slightly. Another bar broke after it had taken a decided set on cold bending. At a cherry red the bars could be forged. ‡

The Effect of Punching on Soft Steel.—Mr. C. H. Benjamin § describes some experiments made on the effect of punching soft steel, to determine the ultimate resistance to shearing of soft steel plate for different forms of punches, and also to determine the effect of punching on the elastic limit and on the tensile strength. Otis steel boiler-plate, $\frac{1}{4}$ inch in thickness, was used, all the pieces being cut from the same plate. The average resistance to punching with common forms of punch was 50,000 lbs. per square inch, whilst with the spiral punch it was only 38,000 lbs. The weakening of the material with these forms of punch was $7\frac{1}{2}$ and 3 per cent. respectively. A considerable

* *Engineering*, vol. liii. p. 534.

† *Ibid.*, vol. liv. pp. 117, 147, 231.

‡ *Revue Universelle des Mines*, vol. xviii. p. 104.

§ Paper read before the Civil Engineers' Club of Cleveland, September 11, 1892. *Journal of the Association of Engineering Societies*, vol. xi. pp. 463-470, one plate; *Engineering News*, vol. xxviii. pp. 274-275.

change in clearance affected the results but slightly, but good or bad centering had a very noticeable effect.

The Testing of Ingot Metal.—F. Kintzle * discusses the relative value of tensile tests, and of tests made across the fibre of the metal, or, in other words, across the direction in which it had been rolled. Hitherto it has been thought that this made but little difference. The author, investigating this subject, finds but little reference to it in literature. Professor Tetmajer has given some examples, which the author quotes, relating to sheets; and in these, while the tenacity is the same in both directions, the elongation is slightly less in the case of the test-pieces taken across the direction of the rolling than in the case of those samples which were cut in the opposite direction along the fibre. Other similar results are also quoted. A joint committee, appointed by the German Architects' Association, the Society of German Ironmasters, and the Society of German Engineers, made a lengthy series of tests to ascertain whether it is possible, in the case of a metal having a tensile strength of from 23 to 27 tons per square inch, and an elongation of 20 per cent., to guarantee the test across the grain of the metal. Another point which formed one of the main objects of the examination was to show how far it is possible to guarantee the following test both along and across the specimen:—Test-pieces both along and across the grain of the metal are to be heated to bright redness, cooled in water of a temperature of 28° C., and then bent in such a manner as to form a strip, the diameter of which at the bend is the same as the thickness of the test-pieces. The tensile tests made numbered 934, and the bending tests 696, and these tests were made by the author in conjunction with Professor Krohn at Sterkrade. In addition, 358 test-pieces, hardened in the manner previously referred to, were hammered into the shape desired, and the results of these latter tests showed that 70 per cent. of all the pieces taken from across the fibre showed small cracks, while the other longitudinal test-pieces were not affected. The results of the various tests are tabulated, and these show that even ingot iron is affected in its quality by the direction of rolling. Across the fibre of the metal the tensile strength becomes irregular, sometimes increasing, and then again decreasing. The elongation is always less. This is most frequently the case with universal iron, and less so for shaped iron and sheets. Thus, while it is possible to guarantee along the

* *Stahl und Eisen*, vol. xii. pp. 686–690.

fibre a tensile strength of from 23 to 27 tons per square inch and 20 per cent. elongation, across the fibre the same result cannot be guaranteed in the case of universal iron, not within 27 per cent., or within 12 per cent. in that of sheets; and even with a given tensile strength of from 22 to 28 tons per square inch along the fibre, and an elongation of 17 per cent., it is not possible to calculate within 10 per cent. in the case of universal iron, nor within 4 per cent. in that of sheets. The bending tests show similar results; and as to cracks on the edges, while the longitudinal test-pieces can be bent to a single thickness as required, pieces taken from across the fibre cannot be bent, without showing such cracks, further than to double the thickness of the test-piece; and, indeed, no works could safely guarantee that the cross-pieces should show no cracks on bending even to this thickness. Universal iron gives the worst results in this test. Weld iron gave much worse results than did ingot metal.

The ingot metal used in the construction of the Fordon-Weichsel bridge is described by Mehrtens.* About 10,000 tons of basic Bessemer and of open-hearth metal was used in the construction of this bridge, and a practical comparison between the two kinds of metal was thus possible. At the Rothe Erde Steelworks, up to May 1892, there had been made 336 charges of basic Bessemer metal, amounting in all to 3100 tons of finished metal, and not one of these charges had to be refused on subjecting it to test. Illustrations are given of the forms of test in use for these charges. Apart from analytical examination, the material is tested—(1) during its manufacture in the converter; (2) as a sample taken from the ingot; and (3) in the form of a test-piece taken from the finished rolled products. Two samples are taken in the converter, after the end of the blow and before the addition of the ferro-manganese, and two after such addition during the casting of the ingots from the ladle. The tests to which these pieces were submitted are described and illustrated, and the results obtained are also given. The composition of the basic Bessemer metal was as follows:—

Phosphorus.	Manganese.	Sulphur.	Carbon.	Silicon.
0·031-0·085	0·26-0·79	0·017-0·071	Under 0·12	Under 0·02

The open-hearth metal gave less satisfactory results when submitted to mechanical tests. Where tested, the composition of this metal proved to vary within the following limits:—

Phosphorus.	Carbon.	Manganese.	Sulphur.
0·03-0·07	0·10-0·14	0·355-0·500	0·04-0·08

* *Stahl und Eisen*, vol. xii. pp. 594-599.

The silicon was not determined.

The tensile strength of the Bessemer metal varied between 24.8 and 27.8 tons per square inch, and that of the open-hearth metal from 24.8 to 28.5. The respective elongations were from 21.0 to 32.5 per cent. in the case of the basic Bessemer metal, and from 20.5 to 37.0 in that of the open-hearth.

Professor L. Tetmajer * points out that experience has shown that— (1.) Well made basic Bessemer iron cannot be distinguished from open hearth metal of an equal degree of hardness. (2.) Basic Bessemer metal can be made for bridge and other construction purposes with an equal degree of certainty and regularity of chemical composition and mechanical properties as is possible with open hearth metal. (3.) While by careless treatment incomplete dephosphorisation is possible both in the basic Bessemer process and in the basic open-hearth, the likelihood of such carelessness is greater in the case of the former than in that of the latter process. (4.) The ingots from normal basic Bessemer blows show irregularities in chemical composition. These, however, vary for the greater part within the limits of analytical error. (5.) The last ingot has a tendency to show a much higher percentage of manganese than those that had previously been cast, owing to some ferro-manganese remaining undissolved until the end. (6.) With a similar chemical composition of the metal, using similar deoxidising agents and the same temperature of tapping, no difference can be observed between the size and position of the pipes of the ingots obtained from the two processes. (7.) Hot casting and the use of ferro-silicon tend to produce blowholes at the sides of the ingot, but even an ingot metal deoxidised with ferro-manganese and spiegeleisen may show bee-cell-shaped blowholes at the sides of the casting, owing to pouring at too high a temperature. (8.) Cold rolling, except at black and blue heats, increases the limit of elasticity and the tensile strength of ingot metal without, as a rule, diminishing its plasticity under treatment and its capacity for being bent in the cold. Annealing is as much as possible to be avoided, rolling at as high a temperature as possible being preferable.

In view of these facts, which the author proves by numerous examples that he gives, the acceptance of ingot iron for construction purposes should depend on carefully watching the metal during its manufacture, and on testing afterwards, both chemically and mechanically. In the case of shaped iron, a large number of hammer tests should be made on the cold metal.

* *Schweizerische Bauzeitung*, 1892, Nos. 19-23.

The steelworks at St. Etienne employs 1600 workmen, and makes plates as a speciality up to $8\frac{1}{2}$ feet in width.* The output, including armour-plate, is about 20,000 tons a year. Weld iron is still largely in use for plates at these works, no less than thirteen different qualities of such plate being made, with tensile strength varying from 20 to 24 tons per square inch, with elongations of 11 to 26 per cent., and with tensile strength across the fibre of 18 to 24 tons per square inch, with an elongation of 4 to 20 per cent. Of ingot metal plates there are four qualities—

	Tensile Strength, Tons per Sq. In.	Elongation, per Cent.
Extra soft	22·2-24·1	30-32
Soft	24·1-26·7	30-26
Semi-hard	28·6-34·9	24-20
Hard	over 34·9	

This metal is made in a basic open-hearth. Plates of 0·16 inch in thickness must withstand five shots at a distance of 32 feet, using hard lead bullets and a French rifle of the 1874 pattern. This latter metal has a tensile strength of 50 to 57 tons per square inch, and 9 to 10 per cent. elongation.

Besides a description of the St. Etienne works, a lengthy account is given by the authors, Revnaud and Mariotte, of other works in the district, which were represented at the St. Etienne Industrial Exhibition.

Tests of Fire-box and Boiler Steel.—The results are published† of a number of tests of steels made by the Wellman Iron and Steel Company, Pennsylvania. The following are some of those obtained with fire-box steel, the test specimens being 8 inches long between the shoulders :—

Ultimate Strength, in Lbs. per Square Inch.	Reduction of Area, in per Cent. of Original Area.	Final Elongation, in per Cent. of Original Length.	Carbon.	Manganese.	Phosphorus.
59,360	50·29	30·00	0·15	0·43	0·020
57,860	42·13	31·70	0·15	0·43	0·020
55,040	63·72	30·50	0·12	0·41	0·013
57,670	55·90	31·92	0·18	0·47	0·015
57,990	49·92	32·12	0·18	0·42	0·011
58,720	48·63	30·75	0·18	0·42	0·011
55,000	53·53	35·62	0·16	0·46	0·015

* *Bulletin de la Société de l'Industrie Minière*, vol. v. pp. 733-843.

† *Iron Age*, vol. xlix. p. 614.

The following are tests of boiler steel :—

Ultimate Strength, in Lbs. per Square Inch.	Reduction of Area, in per Cent. of Original Area.	Final Elongation, in per Cent. of Original Length.	Carbon.	Manganese.	Phosphorus.
59,320	41.40	31.40	0.18	0.42	0.011
56,100	48.72	32.25	0.16	0.46	0.015
55,260	58.46	32.19	0.16	0.54	0.015
57,020	55.05	32.69	0.15	0.46	0.025
54,430	52.19	31.43	0.15	0.48	0.022
61,090	55.38	32.50	0.15	0.46	0.025
59,200	52.07	34.68	0.16	0.51	0.030
58,700	49.91	31.25	0.15	0.47	0.012
61,700	44.27	31.62	0.14	0.42	0.023
57,130	52.08	31.50	0.15	0.47	0.012

Tests of a Large Steel Casting.—The Midvale Steel Company of Nicetown, Philadelphia, describe the steel stem frame made by them for the United States cruiser No. 11, the *Marblehead*. The weight of the casting was 9213 lbs., and the specifications of the Navy Department called for a tensile strength of 60,000 lbs. per square inch, and an elongation of 15 per cent. in the test-bar, $\frac{1}{2}$ inch in diameter by 2 inches between measuring points. The official test of the casting showed a tensile strength of 65,174 lbs. per square inch, elongation 32.2 per cent., and contraction 48.73 per cent.*

Metal Sleepers in Belgium.—M. Janssen † publishes a summary of the experience gathered from the experimental use of metal sleepers in Belgium during the past five years. The sleepers have been found to stand very badly, cracks starting from the bolt-holes. The stone ballast used was rapidly pulverised, and so great indeed has been the difficulty experienced in keeping the permanent way in good condition, that it has cost nineteen times as much as that portion which was laid with creosoted oak sleepers instead of those of steel.

The Causes of Rail Breakages.—Mr. W. R. Hinsdale ‡ discusses the causes to which rail fractures are due. Rails, he observes, are never tested completely. Each individual rail may be, perhaps, and in fact is, looked at, and if the finished rail has a presentable exterior it is passed, regardless of any hidden flaws it may contain, comparatively few of the rails being subjected to thorough tests.

* *Iron Age*, vol. xlix. p. 839.

† *Revue Générale des Chemins de Fer ; American Manufacturer*, vol. li. p. 279.

‡ *Iron Age*, vol. xlix. pp. 814-816, ten illustrations.

1892.—ii.

The ingot of which the rail is to be made is subject to a variety of defects. Then at the top there is either a shrinkage cavity extending downwards in the vertical axis of the ingot to from 15 to 25 per cent. of its total length, or, instead of this, there is a general spongy texture. The sound portion of the piped ingot is generally free from seams and cracks and produces the best results in manufacture, whilst an ingot of spongy texture is sure to develop seams and cracks in working. A too hasty stripping of the hot ingot often causes both transverse and longitudinal cracks, which never weld in the subsequent mechanical treatment to which the metal is exposed. The mere knowledge of the chemical composition is therefore in itself of but little value when judging of the quality of a rail. Specifications should include inspection of the ingots, and the rejection of those which develop defects on rolling. Many irregular transverse surface cracks may frequently be observed when a bloom is passed through the rolls, and, the surfaces oxidising, the finishing rolls, though perhaps rendering the crack impossible to be observed, do not effect a welding together of the oxidised surfaces. The defects therefore still exist, and the value of the rail produced is consequently impaired. The transverse cracks on a bloom often extend for an inch or more into the interior of the mass of metal. It is consequently hazardous to use a bloom that requires surface trimming. Sometimes the faulty condition of the bloom is due to an incomplete reaction in the converter, the reaction continuing in the mould after the ingot has been cast. Some manufacturers purposely induce this slow reaction in the moulds by reducing the percentage of manganese, and this is a common cause of cracks in the blooms. This same reduction in the manganese percentage frequently causes the molten steel to rise 10 or 12 inches in the mould during the cooling of the metal, causing a spongy-textured metal, with a shrinkage cavity commencing at about one-fifth the length of the ingot from the top. The cavities produced become coated with an oxide scale which prevents subsequent welding, thus leading to the phenomenon of piped rails having apparently sound ends. A number of rail sections are described, showing the occurrence and action of flaws in the metal. The United States Government specifications require 35 per cent. of every ingot destined for Government work to be rejected and removed from the top; similar care should be taken in ordinary practice.

The Texture of Rail Heads.—A. Martens* discusses the paper

* *Stahl und Eisen*, vol. xii. pp. 405-415, with sheet of illustrations.

by Wedding* on this subject read before the Society for Railway Construction at Berlin. The author is of opinion that there are a number of important errors in the paper referred to. In the first place, he questions the accuracy of the representation of the microscopic structure of the Goliath rail as shown by Wedding, and the deductions that writer drew from this assumed structure. Professor Martens, with a view to further investigate this question, requested Professor Wedding to permit him to examine the specimen from which the photograph was taken, and the results of this examination are now given. The author shows that the appearance of a central core in the rail head, as observed by Wedding, can be produced by inaccurate treatment during the polishing of the rail for microscopic examination, and by actual measurement this was found to be the cause of the appearance observed in Wedding's specimen.

The author, too, was unable to find any trace of the crystalline mass of metal observed by Wedding as lying at right angles to the direction of the pressure during rolling, and the porous character of the rail, as observed, is also doubted. The author is of opinion that microscopic examination is not likely to become of much practical importance until micro-chemistry has also made considerable progress.

Steel Rails.—Mr. M. White† gives some tests of a so-called toughened steel rail, which has been in use for twenty-two years. The chemical composition is as follows, the second analysis being made on metal from the flange only :—

Carbon.	Manganese.	Phosphorus.	Sulphur.	Silicon.
0·27	0·322	0·055	0·032	0·061
0·46	0·371	0·059	0·046	0·044

Test-pieces were cut from the rail and gave the following results :—

	Annealed.	Unannealed.
Elastic limit, lbs. per square inch	44,480	38,200
Tensile strength, „ „	73,630	71,300
Elongation, per cent.	27·5	28·0
Reduction of area, per cent.	56·78	53·76

Tests of Waggon-Couplers.—Mr. W. Forsyth‡ gives the following results of tests of iron and steel truck couplers of the Master Car-Builders' type.

* *Journal of the Iron and Steel Institute*. 1892, No. I., p. 468.

† *Railroad Gazette*, vol. xxiv. pp. 646-648.

‡ *Iron Age*, vol. xlix. p. 496.

In the testing machine two couplers of the same kind were pulled against each other, and the results of some of these tests show an ultimate strength varying from 80,000 lbs. up to 121,000 lbs. for malleable couplers, and 98,200 lbs. up to 148,800 lbs. for steel couplers. The averages were 100,000 lbs. and 116,300 lbs. respectively. The situation of the fracture in each case is given.

The strength of the material in wrought-iron knuckles is not as great as the bar iron from which they are formed. Broken knuckles of this kind are invariably coarsely crystalline. A tensile test-piece made out of one of these knuckles had an ultimate strength of 48,000 lbs.; elastic limit, 27,300 lbs.; elongation, 15 per cent in 2 inches.

Tabular statements are also given of the results of drop tests, in which the weight of 1640 lbs. struck the knuckle. Iron axles, $4\frac{1}{2}$ inches diameter at the centre, must stand three blows from 10 feet and two at 15 feet from a weight of 1640 lbs., with supports 3 feet apart from centre to centre.

These drop tests show a wide variation in the strength in the different types of couplers, one kind breaking under the first blow from 10 feet, while others endure the full test for iron axles $4\frac{1}{2}$ inches in diameter. The fractures also show not only the weak points in the design, but the poor quality of the material in both malleable iron and cast steel couplers. The steel bars were evidently made of a grade of steel not suitable for the purpose, and the castings had not been properly annealed. Tensile test-pieces, made from the same cast as one design of the couplers, had a strength of only 42,000 lbs. and 49,000 lbs. per square inch, and elongation of 1 per cent. and 2 per cent. in 8 inches. A test of a specimen from another coupler shows that the material is much better adapted to the requirements. It is as follows :—

	Unannealed.	Annealed.
Elastic limit, lbs. per square inch . . .	48,000	43,800
Breaking strain, " " " " . . .	64,000	64,000
Elongation, per cent. in 4 inches . . .	8.25	12.5
Reduction of area, per cent.	11.1	21.3

Steel for Locomotives.—The question of the use of steel plates for locomotive boilers has also been dealt with by the Commission Internationale des Congrès des Chemins de Fer. From a historical review of the use of steel in the several European countries and in the United States, it would seem that mild steel has met with a certain amount of favour, but that hard steels have generally been found unsuitable.

A committee appointed by the Master Mechanics' Association in America has issued a report * on the use of steel in fire-boxes of locomotives. Much attention was directed to the working of steel at a blue heat, and it is shown that, though some steels will stand treatment at this temperature better than others, their use does not seem to offer any advantage. Iron behaved worse than steel at this temperature. Etching with sulphuric acid showed curious results with old fire-box sheets. The central portion seemed to be softened by use, and on planing this out the furnace side expanded while the water side remained straight. This strain in the material does not appear to be relieved by annealing. There seems to be a consensus of opinion that iron is better than steel for boiler-tubes. An experiment was made by putting 114 iron and 113 steel tubes in the same locomotive boiler. After about fifteen months, 17 iron and 64 steel tubes were condemned, owing to pitting and corrosion.

The steel plates used for fire-boxes are frequently found to laminate.† Whether a plate is laminated or not is detected by a sound test. If such a lamination exists at the point where a blow is struck with a hammer, the sound emitted will be "dead." Laminations are caused by several defects in manufacture. If the steel is poured into the ingot in such a way as to cause a "cold shut," or so as to permit air or gas bubbles to remain in what should be the solid part of the ingot, laminations are almost sure to exist in the sheet when finished. If, too, the top of the ingot be cut off too short, the defects present in that part of the ingot, such as bubbles and cinder, are almost sure to cause lamination. The hammer process requires the utmost care. If the hammerer is careless and strikes the sheet unevenly, so that the hammer marks are not removed from the ingot, laminations are likely to result in the sheets rolled from ingots treated in this manner, as the edges of the hammer marks will roll over and form a film on the outside of the sheet. These laminations, if they do not exist when the sheet leaves the rolls, are never likely to occur afterwards, even when the metal is subjected to the severe heat of a locomotive fire-box. It is questionable whether lamination necessarily decreases the strength of a sheet, but if such a sheet were to be used for fire-boxes it would give rise to much trouble and delay, consequent on the necessity for its removal from the locomotive.

* Through *Engineering*, vol. liv. pp. 421, 584.

† *Iron Age*, vol. xlix. p. 813.

Testing Small Chains.—Professor H. S. Hele-Shaw * gives particulars of experiments he has made to determine the strength of small chains. An English welded chain of 0·223 inch in diameter had a breaking strength of 1991 lbs., while the "Triumph" chain of 0·22 inch diameter had a strength of 3773 lbs. This chain is made with a twisted joint in the link by very ingenious mechanism, and nearly the full strength of the metal is retained. A high carbon steel can thus be used in the manufacture, as pointed out by Mr. J. Head. It is stated that a $\frac{3}{4}$ -inch chain has been made by this method with a breaking-strain of 35 tons.

Detail illustrations have been given † of the machine used for making these chains.

Aluminium Steel.—Mr. W. W. Christie ‡ has made a number of tests on the two metals produced by melting together in a crucible the mixtures given below—

Description.	I.	II.
	Lbs.	Lbs.
Wrought iron turnings	10	10
Cast iron turnings	10	5
Steel rail chips	10	15
Aluminium ferro-silicon	2	2

Castings were made 14 inches long by $1\frac{1}{2}$ inch in diameter. The first metal was very fluid but cooled quickly, and made a homogeneous casting with a bright fracture. It could not be touched by a specially hardened cold chisel. Both alloys crumbled under the hammer at a bright red heat, but could be worked slightly at a lower temperature. A somewhat unsatisfactory tensile test gave a breaking load of 44,710 lbs. per square inch. It is suggested that this metal might be used for floor-plates and for pivot-bearings where wear is required. The composition of the aluminium ferro-silicon is not given.

Manganese Steel.—Tetsukichi Mukai § has examined chemically and microscopically two samples of manganese steel containing 12·3 and 10·6 per cent. of manganese, and for comparison a third sample

* Paper read before the British Association, August 1892.

† *Engineering*, vol. liv. pp. 426-427.

‡ Paper read before the American Society of Mechanical Engineers, San Francisco meeting, May 1892.

§ *Studien über Chemisch-Analytische und Mikroskopische Untersuchung des Manganstahls*, Freiberg 1892.

containing 0·6 per cent., in order to discover the reason for the toughening that occurs on sudden cooling. It is found that the specific gravity of manganese steel in the suddenly cooled state is apparently greater than that of the slowly cooled metal, whilst the opposite in general holds true for other steels. Its hardness is also greater as in the case of ordinary steel. The percentage of cement, or non-hardening, carbon, is rather large in manganese steel. This is partly due to the manganese present, which increases the chemically combined carbon. The characteristic feature in the structure of manganese steel are the parallel dark plates on its surface, surrounded by another mass. This is often seen in iron rich in manganese, but is not observed in ordinary steel. The size of the grains, although variable in the suddenly cooled steel, are larger than in the slowly cooled, while the grain in hardened common steel is generally finer. The ductility and malleability of suddenly cooled manganese steel cannot be attributed to the carbon, as that behaves as in common steel, in becoming converted into hardening carbon on quenching. The ductility may be ascribed to the molecular condition, but it is uncertain if this is due to the manganese.

Mr. H. M. Howe * comments on these statements, and questions the power of manganese to cause the retention of carbon in the non-hardening state.

Nickel Alloys.—Mr. J. Hopkinson † finds that the nickel iron alloys, containing 22 and 25 per cent. of nickel, which he has previously examined, are about 2 per cent. less dense when in the magnetisable than they are when in the non-magnetisable state.

Structural Steel.—Mr. G. C. Henning ‡ gives the results of some investigations made on medium and high carbon structural steel used for bridge construction. The tests show that the material used is not uniform when billet-tests, and not tests of the finished articles, are relied upon. Box-girders and other built up sections can be annealed without distortion, and corrosion can be prevented by annealing in closed vessels filled with gas. The shape of the test-pieces, and the methods of making the tests are given, and the results of the tests are

* *Engineering and Mining Journal*, vol. liv. p. 387.

† *Proceedings of the Royal Society*, vol. I. pp. 121-122.

‡ Paper read before the American Society of Mechanical Engineers, San Francisco, May 1892.

tabulated so as to readily show the properties of the material in its various shapes and conditions.

In a paper on iron-mill buildings, Mr. J. W. Seaver* gives the various points to be observed in the construction, a specification of the loads to be allowed, the quality of the material employed, the unit strains of members, &c.

In some tests on full-sized eye-bars, Mr. F. H. Lewis† found differences as great as 5000 to 10,000 lbs. per square inch between the full-sized tests and tests of small specimens, together with a considerable decrease in the elastic limit. The average loss in the elastic limit is 1142 lbs., and in ultimate strength 3595 lbs. The reduction in area is somewhat greater in the specimen-tests, and the elongation on 8 inches is nearly double that on the full-sized bar. Large losses occur generally in bars giving high specimen tests, but bars of 60,000 to 64,000 lbs. show average losses of only 765 lbs. per square inch. The author concludes that these losses will disappear if steel of low tensile strength only is used, and that tests which give high figures in specimen tests are less trustworthy than those which give low ones. The losses in the elastic limit, and in the ultimate strength by annealing, are discussed, and the effect is ascribed chiefly to the softening of the outer skin.

The present method of making the heads of eye-bars, with the upsetting, hammering, and partial heating of the bar, leaves the steel in an uncertain condition as to internal stress, which can only be remedied by annealing. Various tests have been made and are described by Mr. A. C. Cunningham,‡ by quenching from a cherry-red heat in water, fish oil, soap and water, and in boiling water. The oil gives the best results. The hardening of steel in compression members is as important as in eye-bars.

In the fire of the Vienna Panorama building, on April 27, 1892, the cast-iron columns withstood the heat although they were not surrounded by masonry, whilst the light wrought-iron roof trusses very soon became bent. The pillars surrounded by masonry were uninjured, whilst granite was completely destroyed.§

Armour-Plate Trials.—The development of American armour-

* Paper read before the Engineers' Society of Western Pennsylvania, May 17, 1892.

† *Transactions of the American Society of Civil Engineers*, vol. xxvii. pp. 358-402.

‡ *Ibid.*, vol. xxvii. pp. 351-357.

§ *Eisen Zeitung*, 1892, No. 25.

plate is discussed at considerable length by Mr. F. L. Garrison,* chiefly from the standpoint of the metallurgist. The historical side of the question, as far as it concerns the materials used, is gone into, and the recent armour trials in America are fully dealt with by extracts from the official reports and illustrations of the plates. The use of triple alloys with iron and steel is mentioned, and the various hardening processes are described and discussed.

A reproduction of a photograph of a nickel steel plate tried at Indian Head in May 1892, is given in the *Engineer*.† The trial showed that the plate withstood a very heavy impact test without cracking. Another trial has been made at Indian Head on July 23 with a Harvey nickel plate, and a second trial at the Bethlehem proving ground on July 30. Illustrations of both these plates are given. They were 8 feet by 6 feet by $10\frac{1}{2}$ inches in thickness, and both had five shots fired at them. The first of them shows one corner broken off, but no other cracks. The Ellis Tressider compound plate is also illustrated after five rounds were fired at it on August 4, and illustrations of the Holtzer steel projectiles are also given. The plate stood the test well, and a comparison between these various plates is drawn.

An Ellis-Tressider compound plate 8 feet by 6 feet and 10 inches in thickness was tested ‡ on August 4 at Shoeburyness. Five Holtzer armour-piercing projectiles weighing 100 lbs., and striking energy 2637 foot tons, were used. The penetration of two shots was 2·17 and 1·09 inches, the other three remained embedded. All the shot broke up, but the plate was only cracked to a very limited extent.

A trial was made on board the *Nettle* at Portsmouth on November 1 of a nickel steel plate treated by the Harvey process. The plate was 6 feet by 8 feet and $10\frac{1}{2}$ inches in thickness. Five shots were fired from a 6-inch gun, the projectiles weighing 100 lbs. and the charge 48 lbs. The Palliser projectiles indented the plate only about $1\frac{1}{2}$ inch and the Holtzer projectiles broke up after their points had penetrated.§

* *Journal of the Franklin Institute*, vol. cxxxiii. pp. 337-356, 421-453; vol. cxxxiv. pp. 20-42.

† Vol. lxxiv. pp. 49, 147, 240-241.

‡ *Engineering*, vol. liv. p. 210.

§ *Industries*, vol. xiii. p. 467.

CHEMICAL PROPERTIES.

The Carburisation of Iron.—The various theories to account for the carburisation of iron are briefly reviewed by Mr. J. Parry,* who attempts to show that the physical theory of solution may be applicable. At the present time it cannot be considered as proved that true chemical combinations are formed between iron and carbon, whilst, on the other hand, there is a considerable mass of evidence against the explanation of the facts by a simple process of chemical solution. The researches of Percy, Roberts-Austen, Abel, Matthieson, Deville, Graham, Bell, Ledebur, Åkerman, and Spencer, on one side or the other, are mentioned, and from their results the author concludes that the chemical theory of solution does not seem applicable on the whole. By the physical or gaseous theory of solution the substance is dissolved by virtue of osmotic pressure, which Van 't Hoff has shown corresponds to gaseous pressure in space. Boyle's and Charles' laws hold good with regard to dilute solutions, while concentrated solutions may be regarded as gases at high pressures. Avogadro's law also holds to a certain extent. No definite line is drawn between solids and liquids especially when the solid is heated, besides which there is interstitial space between the molecules in solids, so that the law may be applicable, though perhaps with modifications. It is difficult to comprehend the union of stable bodies like carbon and iron, but the application of the law of osmose renders more easy the conception of the transfer of iron to carbon. Taking into consideration the differences between solids and liquids to which the theory has been applied, the difficulty of its further application only becomes one of degree; the quantity of matter dissolved in a given time is simply a function of the temperature, and at low temperatures the effective osmotic pressure is comparable to that of a liquid evaporating under the pressure of its own vapour.

Changes in the Composition of Steel during Mechanical

* *Nature*, vol. xlvi. pp. 283-285.

Treatment.—L. Rürup* describes experiments which have been made in order to ascertain what changes in chemical composition a piece of steel experiences when submitted to mechanical treatment. Two pieces of steel were taken, one drawn out without annealing until the wire broke, and the second after annealing drawn down to 0·27 inch and then examined. Analysis gave the following results:—

Sample I.

Material.	Total Carbon.	Combined Carbon.	Manganese.	Phosphorus.	Silicon.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Original metal — crucible steel.	0·730	0·73	0·203	0·030	0·149
	0·730	0·73	0·208	0·030	0·145
After rolling	0·730	0·72	0·205	0·050	0·212
	0·730	0·72	0·205	0·050	0·212
The wire broken after having been drawn	0·732	0·73	0·205	0·032	0·160
	0·732	0·73	0·210	0·035	0·162
The wire after annealing	0·730	0·71	0·230	0·045	0·208
	0·730	0·70	0·230	0·050	0·205

The second sample gave the following results after having been treated as described above:—

Sample II.

Material.	Total Carbon.	Combined Carbon.	Manganese.	Phosphorus.	Silicon.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Original metal — crucible steel.	0·805	0·80	0·250	0·030	0·200
	0·803	0·80	0·248	0·030	0·202
After rolling	0·800	0·78	0·258	0·044	0·240
	0·800	0·78	0·268	0·049	0·236
The wire broken during the drawing	0·802	0·80	0·255	0·036	0·200
	0·802	0·80	0·250	0·035	0·198
The annealed wire	0·800	0·77	0·265	0·040	0·235
	0·802	0·78	0·260	0·043	0·235

The manganese in each specimen was determined both by precipitation and volumetrically, and the phosphorus both by the magnesia and molybdate methods.

Action of Nitric Acid on Iron.—C. Montemartini† dissolved iron and other metals in nitric acid at 8° C. The evolution of ammonia was found not to be confined to dilute solutions of nitric acid, 0·0051

* *Stahl und Eisen*, vol. xii. p. 471.

† *Gazzetta Chimica Italiana*, vol. xxii. pp. 250-265.

gramme of ammonia, for instance, being formed per gramme of iron dissolved in 47 per cent. nitric acid. The gases evolved by the dissolution of one gramme of iron in excess of 27·5 per cent. nitric acid were as follows :—

	Grammes.
Ammonia	0·02493
Nitrous acid	0·00195
Nitrous oxide	0·00422
Nitrogen	0·00045
Nitric oxide	—
Total gas	0·03553

These numbers agree neither with the hypothesis that the dissolution of the metal is accompanied by the formation of nascent hydrogen, nor with that of the direct oxidation of the metal by the acid. The conclusion arrived at by the author is that nitric acid acts as an oxidising agent in conjunction with the water present, the latter entering into the reaction.

The Relative Corrosibility of Weld and Ingot Iron.—It is stated by Schromm* that he has long observed in ship plates which have been subjected to the action of salt water, that ingot metal is very much more rapidly corroded than weld iron. This he attributes to the greater number of blowholes in the metal. Professor Kupelwieser, on the other hand, attributes this freedom from corrosion possessed by the weld iron to the layers of slag which are pressed into the metal during its manufacture.

Alloy of Antimony and Iron.—According to Professor F. Comelli,† an alloy of 400 grammes of fresh iron filings with 200 grammes of antimony emits red and white sparks when rubbed by a coarse file. This is ascribed to the low heat of ignition of the alloy.

Triple Alloys of Iron, Manganese, and Aluminium.—In a paper read before the British Association, Mr. T. W. Hogg‡ observes that while both manganese and aluminium reduce or destroy the magnetic property of iron, the opposite result is observed when both are present together.

Thus each of the two alloys of which analyses are given below was strongly magnetic. They were obtained by pouring into a crucible

* *Stahl und Eisen*, vol. xii. p. 589.

† *Il Progresso*, through *Engineering and Mining Journal*, vol. liiii. p. 641.

‡ *Chemical News*, vol. lxi. p. 140.

containing 5.56 lbs. of fused aluminium, 99.5 per cent. fine, 50 lbs. of 82 per cent. ferro-manganese. The mass became almost immediately very pasty, and was poured at once. When about two-thirds of the alloy had been poured, the remainder suddenly solidified. It was left to itself in the crucible for twelve months, at the end of which time complete disintegration had taken place. The other portion showed no disintegration. The analytical results were as follows:—

Description.	Disintegrated Alloy.	Non-Disintegrated Portion.
	Per cent.	Per cent.
Iron	10.80	14.80
Manganese	54.86	75.40
Carbon	2.32	5.55
Aluminium	25.34	3.05
Silicon	0.79	0.89
Sulphur	trace	trace
Phosphorus	0.11	0.18
Copper	0.07	0.08
Totals	94.29	99.95

The disintegrated portion had the specific gravity of 3.61. The fluid portion of the alloy was almost as strongly magnetic as iron itself, and the portion which solidified was also strongly magnetic, although the quantity of both the manganese and aluminium was in itself sufficient to destroy the magnetic power completely if only one of these two elements had been present instead of both.

The deficiency in the first analysis is ascribed to oxygen, and Mr. G. Craig * suggests that the disintegration may be due to the oxidation rather than the oxidation being a sequel of the disintegration.

* *Chemical News*, vol. lxvi. p. 160.

CHEMICAL ANALYSIS.

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I.—ANALYSIS OF IRON AND STEEL.

The Separation of Iron from other Elements.—J. W. Rothe* shows that ferric salts dissolved in hydrochloric acid can be extracted with ether from this solution, whilst ferrous salts must be converted into ferric ones before this treatment, as they are not so readily soluble in ether. Manganous salts and those of chromic oxide, nickelous oxide, and alumina do not pass into solution in the ether used, but small quantities of cobalt and of copper are so extracted. These can, however, be again extracted from the ether solution by shaking it with hydrochloric acid of the specific gravity 1.104, the slight quantity of iron which passes into the acid being again regained by further treatment with ether.

In analysing a steel the author dissolves 5 grammes of the metal in 40 cubic centimetres of hydrochloric acid of the specific gravity 1.124 (at 19° C.), heating gently on the water-bath. The solution is then evaporated to dryness, first on the water-bath and then on an air-bath of a temperature of 120° C. The dry residue is dissolved in 20 cubic centimetres of the same hydrochloric acid, and heated to boiling. After dilution with three times the volume of water, the silica is filtered off. The filtrate is evaporated in a porcelain dish till hydrochloric fumes begin to escape, and then 10 cubic centimetres of concentrated hydrochloric acid are added, and when boiling 2 to 2½ cubic centimetres of nitric acid of the specific gravity 1.4 are added drop by drop. Finally, the solution is evaporated on the water-bath

* *Mittheilungen aus d. kgl. techn. Versuchsanstalten zu Berlin*, vol. x. p. 132.

until it has attained the consistency of a syrup, or until basic iron chloride begins to form. The solution is now of the bulk of about 10 cubic centimetres, and is transferred to a separating flask of peculiar construction, where it is diluted with 55 or 60 cubic centimetres of hydrochloric acid of the specific gravity 1.124, and then extracted twice with ether. If much cobalt or copper has passed into solution both the first and the second ether extract must be shaken up with 10 cubic centimetres of the dilute hydrochloric acid already referred to. If alumina is present in the iron solution to be treated with ether, care must be taken that the solution is perfectly clear, and that no basic alumina salts are present. This method has already been used by the author for over one hundred analyses of steel and of iron alloys.

The Determination of Carbon.—C. Reinhardt* describes an apparatus for the determination volumetrically of the total carbon in iron and steel. This apparatus consists in principle of a generating-flask with attached absorbing and measuring vessels. The carbon is burnt completely to carbonic anhydride by passing the products of the oxidation by bichromate and sulphuric acid over a spiral of palladium wire kept at a red heat by a current of electricity. The absorption arrangements are complete, and that for the reading off of the mercury level is also such as to lead to accurate determinations being obtained with great facility. The method of using this apparatus is also described.

H. Rubricius † describes a modification of the Vogel apparatus for the determination of carbon in iron and steel. The apparatus as modified is practically a Bunte burette as used for gas analysis. A single 3-way glass stopper is used instead of the complicated arrangement originally suggested, and the apparatus is not only simpler but much less liable to fracture.

Filtering Carbon Residues.—W. P. Barba ‡ refers to the filtration of the carbon residues left on dissolving steel in ammonium-copper chloride. Sometimes this residue is very hard to filter properly, but it may be filtered rapidly if, after the solution has been effected, the solution is allowed to stand for fifteen minutes to admit of the carbon settling. As much as possible of the liquid is then decanted, some

* *Stahl und Eisen*, vol. xii. pp. 648-656, with six illustrations.

† *Chemiker Zeitung*, vol. xvi. p. 819.

‡ *Stahl und Eisen*, vol. xii. p. 380.

fine asbestos is mixed in with the carbon, and the whole filtered. The filtering is then effected with ease.

The Determination of Manganese.—L. Schneider * dissolves 2 grammes of the steel in 200 cubic centimetres of a sulphuric acid, consisting of 1 part of acid to 2 of water. It is oxidised by boiling with 5 cubic centimetres of nitric acid, the boiling solution being digested for fifteen minutes with lead peroxide. A further addition of lead peroxide is then made, and the flask cooled down, shaking the solution frequently. Any chromium present is oxidised to chromate, and the manganese to permanganate. The solution is filtered through asbestos, diluted to a litre, reduced by the addition of an excess of ammonium ferrosulphate, as in the case of chromium, and the excess so added determined by titration. By making a separate determination of the chromium by boiling with the lead peroxide, the percentage due to the presence of this element can be subtracted from the titration result, the residue representing the manganese that was to be determined.

H. Rubricius † dissolves 2 grammes of the metal placed in a small beaker in as little hydrochloric acid as possible, dilutes the solution somewhat, and then oxidises with a few drops of nitric acid. The solution is then diluted with water to from 500 to 600 cubic centimetres, and very accurately neutralised with sodium carbonate. After the neutralisation is complete, the iron is precipitated by a milk of zinc oxide, too large an excess of the precipitant being avoided. At first the precipitate is gelatinous, but on the addition of more zinc oxide, and stirring strongly, it passes into a more granular form, which rapidly settles. An addition is now made of from 2 to 3 grammes of magnesium sulphate, and the whole is slightly heated. It is then immediately titrated with permanganate. The end point is readily observed owing to the extent to which the dilution has been carried, the precipitate settling below a clear solution. At the commencement of the titration, especially if the metal under examination contains from 1 to 2 per cent. or more of manganese, the supernatant clear solution shows a brownish tinge, but this disappears as the titration progresses, and does not interfere with the final reddish colour.

Mr. C. P. Van Grundy ‡ gives some notes on Textor's rapid method

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. p. 237.

† *Zeitschrift für Angewandte Chemie*, 1892, p. 274.

‡ Paper read before the Chemical Section of the 'Engineers' Society of Western Philadelphia, May 24, 1892.

for the determination of manganese in steel. This method is as follows:—Dissolve 0.1 gramme of steel in 15 cubic centimetres of nitric acid of the specific gravity 1.20, boil till free from brown fumes, add 15 cubic centimetres of hot water, and while boiling introduce half a gramme of lead peroxide. Boil three minutes, filter through asbestos, and wash with a 2 per cent. solution of nitric acid. Titrate with arsenious acid till the pink colour disappears. The author notes the precautions to be employed, and describes the best form of filter to use, with a view to shortening the time required for filtration. The time so required is about ten minutes, and concordant results are readily obtainable.

The Determination of Phosphorus.—A modification of the Hundeshagen method is described by Dr. M. Rothberg and W. A. Auchinvole.* Two grammes of the steel are dissolved in 20 cubic centimetres of nitric acid in an Erlenmeyer flask. When the violent reaction has ceased, the contents of the flask is heated to boiling, oxidised with potassium permanganate, the precipitated manganese peroxide dissolved by the use of sugar or ferrous sulphate, and the whole boiled for another minute, allowed to cool to 40° C., 50 or 60 cubic centimetres of molybdate solution added, shaken for a minute or so, allowed to stand in a warm place for five minutes, and then filtered in the usual way, washing with dilute nitric acid, and then with a solution of 3 grammes of potassium nitrate in a litre of water.

The precipitate, together with the filter, is charged into a small beaker, and then from a burette a solution of caustic soda is run in in a quantity sufficient to dissolve the precipitate. This is then diluted to 50 cubic centimetres with water, two drops of phenolphthalein are added, and the whole titrated back rapidly with nitric acid. If the solutions have been so chosen that 1 cubic centimetre of alkali is equivalent to 1 cubic centimetre of acid, then the number of cubic centimetres of combined alkali used, multiplied by 0.02, gives the percentage of phosphorus contained in the steel, assuming that $\frac{n}{6}$ solutions have been employed.

H. Neubauer† observes that ammonium magnesium phosphate, when strongly heated, loses a portion of its phosphoric acid by volatilisation, if the precipitate had been produced in a solution of ammonia

* *Journal of Analytical and Applied Chemistry*, vol. vi. pp. 243-245.

† *Zeitschrift für Anorganische Chemie*, vol. ii. pp. 45-50.

salts, with free ammonia, and exceeding a certain degree of concentration. This is probably due to the phosphoric acid in the presence of much ammonia salts not being precipitated completely in the form of the dimagnesium ammonium phosphate, $\text{Mg}(\text{NH}_4)\text{PO}_4$, but partially in the form of the monophosphate $\text{Mg}(\text{NH}_4)_2(\text{PO}_4)_2$. This on heating is decomposed, metaphosphate being formed, which in turn becomes pyrophosphate, with liberation of phosphoric anhydride, as shown by the equation, $2\text{Mg}(\text{PO}_3)_2 = \text{Mg}_2\text{P}_2\text{O}_7 + \text{P}_2\text{O}_5$.

Mr. E. K. Landis * finds that the precipitation of ammonium-magnesium phosphate in the citric acid process for the determination of phosphorus in pig iron is considerably hastened by constant stirring. In view of this a mechanical stirrer, worked by a small water-wheel, is used. The precipitation takes half-an-hour, being only a quarter of the time that would be required if the solution were left standing, and the results are quite as accurate. The process used for the determination is described.

R. Zimmermann † describes a method for the determination of phosphorus in pig iron and steel. It is based on the observation of E. Metz, that a precipitate of ammonium phosphododekamolybdate, containing 1.73 per cent. of phosphorus, has the specific gravity 3.252. Using an apparatus of known volume and weight, filled with a solution also of known volume or weight, the displacement of this solution by the precipitate to be determined, gives a rapid method for the calculation of the phosphorus. As such solution the author uses a 1 per cent. solution of nitric acid, with the specific gravity 1.002. Five grammes of the metal in which the phosphorus is to be determined are dissolved in the usual way in nitric acid of the specific gravity 1.2, oxidised with potassium permanganate, the manganese peroxide reduced with hydrochloric or oxalic acid, to the clear solution ammonium nitrate added, and then the phosphorus precipitated by a large excess of molybdate solution. After shaking well for a few minutes the precipitate is allowed to settle, and the clear solution removed in about twenty minutes by decantation. In the following operations care must be taken to avoid temperature alterations, with their concomitant changes in the density of the solution, &c. The precipitate is washed on a filter with the 1.002 nitric acid solution, and is then washed with the same solution into the measuring

* *Transactions of the American Institute of Mining Engineers*, Lake Champion meeting (advance proof).

† *Stahl und Eisen*, vol. xii. pp. 524-527.

apparatus—the pyknometer. After closing and drying this, it is weighed with its contents. The further calculations are easy, and are given by the author in detail.

The Determination of Sulphur.—L. Blum* passes the sulphuretted hydrogen produced on solution of the metal, into ammoniacal hydrogen peroxide, or into bromo-hydrochloric acid. To destroy the action of the gelatinous hydrocarbon compounds which form in the bromo-hydrochloric acid, this latter is placed in an Erlenmeyer flask of 400 cubic centimetres capacity, a piece of ash-free filter paper is added, and then the bulk of the acid neutralised by ammonia. When using hydrogen peroxide this is acidulated with bromo-hydrochloric acid, precipitated with barium chloride in the usual manner, and then boiled down to one-half of the original volume. The filter-paper added as above-mentioned is broken up into its fibres, to which the gelatinous bromine compounds attach themselves, and the solution clears so rapidly that after heating for about half an hour filtration can be effected.

The same author describes† and illustrates an apparatus for the absorption and oxidation of the sulphuretted hydrogen evolved on the solution of the steel in acid. It consists of a glass bulb attached to a long tube, fused into a similar glass arrangement. The gas can thus be made to pass up through a long column of the oxidising solution employed.

W. Thörner‡ publishes an illustration of an apparatus for use in the determination of sulphur in steel. It consists of a flask provided with an indiarubber stopper through which a funnel tube passes. Below the funnel is a glass cock, and below this again a tube enters at the side. The flask itself has a tube, rising upwards for a short distance, blown into the neck, and this bending downwards is connected with a bulb absorption apparatus.

The Determination of Chromium.—L. Schneider§ dissolves 2 grammes of the steel in 100 cubic centimetres of dilute sulphuric acid, consisting of 1 part of acid to 10 of water. When the solution is complete, the ferrous oxide is oxidised by the addition of 5 cubic centimetres of concentrated nitric acid, the whole being boiled

* *Zeitschrift für Analytische Chemie*, vol. xxxi. pp. 290-292.

† *Zeitschrift für Angewandte Chemie*, 1892, p. 466.

‡ *Stahl und Eisen*, vol. xii. p. 527.

§ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. p. 236.

until the brown fumes have ceased to appear. To the boiling solution about 5 grammes of lead peroxide is added, the solution being kept at the boil for a quarter of an hour. After the oxidation of the chromium the solution is diluted with water, allowed to cool, and the excess of lead peroxide filtered off. The filtrate is then made ammoniacal and boiled for a few minutes. Any manganese present, which would by this operation have been converted into permanganate, decomposes rapidly and completely, and the solution remaining above the ferric oxide should appear of a clear yellow colour. If the percentage of chromium in the steel is so small that the yellow colour it imparts to the solution cannot with certainty be determined, the ammoniacal solution is filtered and the filtrate acidulated with sulphuric acid, by which means it becomes possible to detect even slight traces of chromium by the yellow colour imparted to the solution. If the percentage of chromium reaches 0.1, this filtration of the ammoniacal solution is unnecessary, as the solution will be distinctly yellow. In that case the precipitated ferric oxide is dissolved direct by a little sulphuric acid. If, however, it is discoloured by precipitated manganese dioxide, filtration is necessary. The clear solution is diluted to at least 1 litre, and the chromium determined by the addition of an excess of ammonium ferrosulphate and titration of the excess of this salt so added.

In the case of ferrochromium rich in the latter metal, in order to convert the whole of the chromium into chromate, it is necessary to boil the sulphuric acid solution for about an hour, and then to add a further addition of lead peroxide and to repeat the operation.

The process recommended by Mr. T. W. Hogg* for the determination of chromium in steel is a modification of Galbraith's method. He uses a stronger acid, consisting of one part of sulphuric acid with two of water, and boils vigorously. The solution is highly coloured, the chromium salt masking the colour of the ferrous sulphate. As little as 0.1 per cent. is sufficient to colour the solution.

Dr. J. Clark† discusses the determination of chromium in chromium-iron alloys. He refers to the statement of Warren that ferrochromium is readily soluble in strong sulphuric acid, but he has found that the solution is not complete. The various other methods of opening up this alloy, such as fusion with sodium carbonate and nitre, or with other fusion mixtures, are also referred to. The author prefers to

* *Journal of the Society of Chemical Industry*, vol. x. pp. 340-341.

† *Ibid.*, vol. xi. pp. 501-504.

heat the alloy with five times its weight of a mixture consisting of two parts of freshly calcined magnesia and three of finely pulverised sodium hydrate. On heating gently, a rapid oxidation takes place. After extracting with water, the residue is reheated as before. All the chromium will pass into solution and can then be determined in the usual way. Instead of the magnesia-soda mixture, one of lime and soda may be employed. In the case of poorer alloys, such as chromium-steel, the sulphur and carbon-bisulphide processes are far the best. On heating in sulphur vapour Cr_2S_3 and FeS are formed, but heating in carbon-bisulphide vapour gives still better results. The mixed sulphide can be converted into oxide by roasting, and the remainder of the process presents no difficulties.

The Determination of some Rarer Elements in Steel. — L. Schneider* determines in the following manner the percentages of aluminium, titanium, tin, antimony, vanadium, calcium, and magnesium in steel:—12 grammes of the steel are dissolved in 150 cubic centimetres of nitric acid of 1.2 specific gravity, the heating being continued until the solution is complete. Then 12 grammes of tartaric acid is added. This quantity is sufficient to maintain the whole of the ferric oxide dissolved when the solution is made ammoniacal. Next a mixture of 200 cubic centimetres of water and an equal quantity of strong ammonia is added to the iron solution. A considerable precipitate is formed, but this passes into solution again on heating till the solution is almost at a boiling heat. The solution is then clear and of a dark colour. It is transferred to a 2-litre measuring-flask, largely diluted with hot water, and the iron and manganese precipitated by ammonium sulphide. To avoid using an excess of ammonium sulphide about 50 cubic centimetres of ammonia is saturated with sulphuretted hydrogen after dilution with an equal quantity of water. This is then used as the precipitant. After being well shaken the contents of the flask is diluted to the 2-litre mark and then allowed to settle, either in the flask, or, and preferably, after transferring to a large beaker. It is then filtered through a dry filter, which must have been well washed with hydrochloric acid and then with hot ammonia water. If this is not done small quantities of calcium and magnesium pass into the filtrate from the filter-paper, even when the solution being filtered is ammoniacal. This might lead to the erroneous assumption that both these elements were present in the steel under examination. Of the filtrate, 1.5 litre, equivalent to 9

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 471-473.

grammes of the steel, is evaporated in a platinum basin. As the solution nears dryness, concentrated hydrochloric acid is added at intervals. Gaseous decomposition-products of the tartaric acid are in this way formed, and the residue evaporates quietly. It is finally heated to dull redness. Next by moistening with a few drops of sulphuric and hydrofluoric acids the silica present is driven off. Then since both titanitic and vanadic acids are soluble in ammonia in the presence of tartaric acid, the residue, in addition to alumina, may contain these two acids, as well as stannic acid, antimonious acid, lime and magnesia. These latter would be only present in exceptional cases, and their determination in the presence of iron is a matter of no difficulty. To determine the alumina contained in the residue, it is fused with sodium carbonate, the fused mass boiled with sulphuric acid, and the alumina precipitated from the clear solution by ammonia. In the sulphuric acid solution of the alumina the presence of titanium may be detected by the addition of a few drops of hydrogen peroxide, the slightest traces of which would then lead to a brilliant orange yellow colour. This reaction is so delicate that it may be used as a very accurate colorimetric method of determination of the titanium. For this purpose it is necessary to prepare a solution 1 cubic centimetre of which will contain exactly 1 milligramme of titanitic acid. For the colorimetric determination of the titanium existing in the acid alumina solution, a definite quantity of this standard solution would be diluted with its own bulk of hydrogen peroxide, and the solution so obtained used as a standard of comparison in the ordinary way. If on fusing the alumina with sodium carbonate the fused mass becomes of a greenish hue, it must be tested for vanadic acid. In the filtrate from the alumina the lime and magnesia can be determined in the usual way.

W. Schoeniss,* in determining aluminium, dissolves 5 to 10 grammes of the steel in a platinum dish in dilute nitric acid, evaporates to dryness, heats the residue over a Bunsen burner, and then heats to redness until the last trace of nitrous fumes has disappeared. The resulting oxides are ground fine in an agate mortar, and then fused in a silver dish with potassium hydrate free from alumina and heated to redness. After cooling, the fused mass is treated with hot water, filtered, and washed thoroughly. The filtrate is acidulated with hydrochloric acid, and the alumina present precipitated in the ordinary manner with ammonia, ignited, and weighed. In this way in basic open-hearth metal the alumina can be obtained perfectly free from silica, but from

* *Stahl und Eisen*, vol. xii. p. 527.

acid-made steel, crucible steel, and ferro-aluminium the alumina obtained always contains silica. In this case, after weighing the alumina it is treated in a platinum crucible with hydrofluoric acid, evaporated, and ignited, the silica, of course, being thus driven off. In filtering care must be taken to use well-washed filters, and the beakers themselves should be rinsed out with acid. The results obtained in this way are accurate, the writer having frequently to determine the aluminium in steel which contains but 0.1 per cent. of aluminium. For such a small percentage as this at least 10 grammes of the steel should be taken.

The Determination of Slag in Wrought Iron.—When puddling impure iron, the yield of puddled bar is greater than when purer materials are used, but the subsequent loss in working is also greater. These effects are investigated by Mr. A. E. Barrows and Mr. T. Turner,* whose researches do not bear out the supposition that the losses are due to the slag contained in the puddled iron. Best and common bar and sheet were made from two samples of different quality. The yield of common puddled bar was 6.5 per cent. greater, but the loss in reheating was 1.5 per cent., showing a balance in favour of the common iron of 5 per cent. The composition of the samples was as follows:—

Description.	Best.		Common.	
	Bar.	Sheet.	Bar.	Sheet.
Carbon	0.060	0.035	0.045	0.032
Silicon	0.228	0.168	0.275	0.221
Phosphorus	0.178	0.175	0.589	0.390

This shows that silicon is equally removed, but only to a slight extent, in each case, while phosphorus was much reduced in common iron and but scarcely affected in the best. This does not favour the view that much more slag is removed in one case than the other.

By dissolving the iron in a cold solution of sodium copper chloride, the results below were obtained:—

	Best.		Common.	
	Bar.	Sheet.	Bar.	Sheet.
Slag, per cent.	3.83	2.58	3.85	2.85
Loss	1.25 per cent.		1.00 per cent.	

* *Journal of the Chemical Society*, vol. lxi. pp. 551-557.

For practical purposes the weight of slag in common and best iron may be taken as identical, and that each loses about the same weight of slag on reheating and working. The additional loss on reheating impure iron is due chiefly to the elimination of phosphorus, probably in the form of ferrous phosphate.

The International Iron and Steel Standards.—A report by the committee of the British Association on the international iron and steel standards has appeared. The results obtained from the four samples by Mr. W. Jenkins, Mr. J. S. Packer, Mr. J. Pattinson, Mr. E. Riley, and Mr. J. E. Stead are now published, and show a fairly close agreement. A short account of the methods adopted by the four last-named analysts is also given. The means of the several results are as follow :—

Standard.	1.	2.	3.	4.
	Per cent.	Per cent.	Per cent.	Per cent.
Carbon	1·414	0·816	0·476	0·151
Silicon	0·263	0·191	0·141	0·008
Sulphur not more than	0·006	0·007	0·008	0·039
Phosphorus	0·018	0·014	0·021	0·058
Manganese	0·259	0·141	0·145	0·130

Standard No. 5 has been prepared, and will be distributed as soon as possible. The American committee have nearly finished their work on the first four samples, but the German, French, and Swedish reports have not yet appeared.*

The Analysis of Commercial Aluminium.—Messrs. A. E. Hunt, G. H. Clapp, and J. O. Handy† point out that aqua regia dissolves aluminium, even when the nitric acid is in large excess. Silicon exists in the metal in both forms. The total silicon is found by dissolving in nitro-hydrochloric acid and evaporating with sulphuric acid, the insoluble graphitoidal silicon together with the silica being fused, after ignition, with sodium carbonate, and the fused mass dissolved and evaporated with sulphuric acid, as before. Iron and copper may be determined by the usual methods of titration. In determining the aluminium, the copper, &c., is first precipitated by sulphuretted hydrogen, and then, in the nearly neutral solution, the

* *Industries*, vol. xiii. pp. 282-283.

† *Journal of Analytical and Applied Chemistry*, vol. vi. pp. 24-33; *Chemical News*, vol. lxx. pp. 223-225, and 235.

alumina is thrown down by ammonium phosphate, with the addition of sodium hyposulphite, the solution being boiled until all the SO_2 has been driven off. After re-solution and re-precipitation, the precipitate is ignited and weighed as AlPO_4 . Titanium, if present, is determined by dissolving the metal in caustic potash, filtering, fusing the residue with potassium hydrogen sulphate, dissolving, separating the silica by hydrofluoric acid, if necessary, and finally precipitating the titanium from the acid sulphate solution by saturation with sulphurous acid, and then igniting the precipitate for titanic anhydride. Chromium is also determined by dissolving the metal in a caustic potash solution. The washed residue contains the chromium. The residue is fused with potassium hydrogen sulphate, and then with sodium carbonate and nitre, the chromate solution being afterwards reduced and the chromium precipitated as hydroxide by ammonia, any aluminate being first decomposed by ammonium chloride.

II.—ANALYSIS OF IRON ORES AND SLAG.

The Analysis of Chrome Iron Ore.—E. Waller and H. T. Vulté* mention the various methods which have been suggested for the decomposition and solution of this mineral. These they discuss, and state that when using fusion, a good method consists in fusing one gramme of the sample with six times its weight of Dittmar's flux in a platinum dish, dissolving in water, filtering, evaporating, and adding a little ammonium nitrate occasionally until the last addition fails to give any odour of ammonia on heating the solution. Then continue the evaporation to dryness, moisten with a few drops of nitric acid, and heat to dryness again. Take up with water containing a few drops of nitric acid, add hydrochloric acid and sulphurous acid, or a little ammonium sulphite, boiling off the excess of SO_2 . Then neutralise with ammonia and boil, adding a little ammonium sulphide. Redissolve in hydrochloric acid, and re-precipitate as before. Ignite and weigh as Cr_2O_3 .

The determination of chromium is also discussed by A. Baumann,† especially the methods involving the use of hydrogen peroxide as an oxidising agent, destroying this by boiling the alkaline solution, and after neutralising by sulphuric acid, determining the chromic acid by

* *School of Mines Quarterly* (New York), vol. xiii. No. 3.

† *Zeitschrift für Angewandte Chemie*, 1892, p. 113.

gas-volumetric methods, 1 cubic centimetre of oxygen corresponding to 2.246 milligrammes of CrO_3 . In the case of chrome iron ore, the author first opens up the mineral by fusion with soda and nitre, the presence of large quantities of nitric acid interfering with the accurate determination of the chromic acid.

The Determination of Manganese.—Messrs. J. and H. S. Pattinson* conclude, from some investigations on the actions of oxides of manganese when heated in the air, that volumetric methods are far preferable to gravimetric methods for the determination of manganese, both as regards accuracy and ease of execution.

The Separation of Ferric Oxide and Alumina.—Messrs. F. Beilstein and R. Luther† separate these two oxides by a method based on the unequal solubility of their basic nitrates in water. By repeated evaporation of a solution of aluminium nitrate about half the nitric acid originally present is driven off. The basic nitrate remaining is readily soluble in water, and is not precipitated in the cold by a solution of alkaline sulphates. Basic ferric nitrates, on the other hand, similarly formed by evaporation of the nitrate, are only partially soluble in water in the cold. Still they dissolve, but the solution, though depositing nothing, is far from clear, the iron being present in the colloid form, ammonia only gradually causing a precipitate. A few drops of a sulphate solution added causes a precipitate even in the cold, basic nitrates being precipitated, no sulphuric acid being detectable in the precipitate. The authors employ this variation in the behaviour of the aluminium and iron nitrates as a means for their quantitative separation. They evaporate to dryness the nitric acid solution of the mixed oxides, and heat the residue on a sand bath until all nitric acid fumes have ceased to be evolved. It is then treated with boiling water, a few drops of ammonium sulphate are added, and the whole filtered. All the alumina passes into the filtered solution in the form of a basic nitrate, whilst the iron remains as an insoluble residue on the filter.

W. H. Krug‡ discusses the determination of alumina and ferric oxide in the presence of phosphoric acid. He shows that the alcohol method is inaccurate, and recommends that of M'Elroy. In this, after precipitating the phosphorus from 1 gramme of the substance, diluted

* *Journal of the Society of Chemical Industry*, vol. x. pp. 333-338.

† *Bulletin de l'Académie Impériale des Sciences de St. Petersburg*, vol. xiii. p. 149.

‡ *Stahl und Eisen*, vol. xii. p. 470.

to $\frac{1}{2}$ litre, by ammonium molybdate, the solution is filtered through a dry filter-paper, and two portions of 200 cubic centimetres each are taken for the assay. Some solid ammonium nitrate is added to the solution, dissolved, the solution cooled, and an excess of ammonia added. The precipitated hydrates of iron and aluminium are then redissolved with nitric acid and re-precipitated by ammonia as before. They can thus be obtained free from molybdic acid. In the filtrate the other oxides can be determined provided that the precipitation is effected in the cold, as otherwise molybdic acid will also be precipitated.

The Analysis of Basic Bessemer Slag.—O. Förster* refers to the agreement that was arrived at by the association of experimental agricultural laboratories in Germany as to the method of analysis to be used in the determination of the agricultural value of basic slag. It was agreed to decompose the slag by concentrated sulphuric acid, as solution in nitric acid, or nitro-hydrochloric acid, tends to oxidise the phosphorus of the iron phosphide into phosphoric acid, and the solution in hydrochloric acid is not adapted to the application of the citrate method, hydrochloric acid taking into solution much larger quantities of foreign substances than sulphuric acid. The ammonium magnesium precipitate is consequently much more impure. These impurities are stated to average as much as 6.33 per cent. of the magnesium pyrophosphate. Since the above agreement was arrived at the value of the citrate method has become more than doubted. The degree of solubility of the ammonium-magnesium phosphate in ammonium citrate appears to vary greatly with the composition of the slag under analysis. It has become customary, therefore, to adopt the molybdate method in combination with decomposition of the slag by sulphuric acid. Concentrated sulphuric acid, however, the author shows, should not be employed, the diluted acid, or hydrochloric acid, giving much better results when used as the solvent. In view of the fact that tetra-calcium phosphate is completely soluble in dilute citric acid solution, and that the residues of slag treated by this solvent often show the presence of appreciable quantities of phosphoric acid, it is doubtful whether strong acids should be employed at all as solvents, as it is only the phosphorus present as the tetrphosphate, which is of any manurial value.

A. F. Hollmann† recommends a mixed Classen-Jones method for this purpose. In the Classen method some manganese is precipitated

* *Chemiker Zeitung*, vol. xvi. p. 1596.

† *Ibid.*, p. 1471.

with the lime. This is then re-precipitated by the Jones method as sulphate from an alcoholic solution, and the precipitate is then free from both iron and manganese. A solution of 1 gramme of the basic slag, of small bulk, has added to it 20 cubic centimetres of a neutral solution of potassium oxalate, containing 1 part of salt to 3 of water, and is digested on a water-bath until the precipitate is of a clear white colour, and free from any lumps. It is then filtered and washed until no oxalic acid can be detected in the filtrate. The precipitate is washed out, and finally the filter-paper washed with hot dilute hydrochloric acid. The precipitate is dissolved in about 15 cubic centimetres of hydrochloric acid, and is then brought to about the bulk of 25 cubic centimetres. To this solution 10 cubic centimetres of dilute sulphuric acid (1 of acid to 5 of water) is added, and then 150 cubic centimetres of alcohol of a strength of 95 per cent. In about three hours the precipitate is filtered off and washed with alcohol of the same strength as the above until no acid reaction is to be detected with methyloange. It is then heated until of constant weight in the usual manner. This joint method gives very accurate results.

Dr. A. F. Jolles* discusses the solvents to be employed in this determination. In decomposing with sulphuric acid there is always a certain percentage of the phosphorus left in the insoluble residue, the quantity varying with the percentage of lime present in the slag. A similar result is observed when using hydrochloric acid as a solvent. The ordinary Albert method, using hydrochloric acid and ammonium citrate, gives results which are far too high, silica always passing into the magnesia precipitate. The author proposes the following modified method: 5 grammes of the finely powdered slag is moistened with water, evaporated to complete dryness with 40 cubic centimetres of hydrochloric acid of 20° B. The residue is heated to 120° C., cooled, moistened with hydrochloric acid, taken up with water and filtered. The filtrate is diluted to 500 cubic centimetres, and to 50 cubic centimetres of this is added 15 cubic centimetres of a solution of 400 grammes of citric acid in a litre of ammonia of 0.9 specific gravity. The phosphorus is then precipitated in the usual manner by magnesia mixture, the precipitate being dried, ignited, and weighed in the ordinary way. By this method the results obtained agree well with those obtained by the molybdate method, care having been taken to avoid the presence of the soluble silica, which rendered the method as originally proposed inaccurate.

* *Zeitschrift für Analytische Chemie*, vol. xxxi. pp. 516-519.

M. Spica,* while describing the more usual methods, gives also the following, in which he attacks basic slag with sulphuric acid, evaporating the solution almost to dryness, and so driving off nearly all the excess of sulphuric acid. By extracting with absolute alcohol all the sulphates, ferric oxide, alumina, silica, &c., remain undissolved. The solution is filtered through a dried filter-paper, washed with absolute alcohol, evaporated to drive off the alcohol, neutralised with caustic soda, and reduced to a definite volume. This solution contains all the phosphoric acid that was in the slag. In it the author determines the phosphoric acid volumetrically, using as a standard solution one of potassium-iron alum, an aqueous solution of salicylic acid serving as an indicator. This assumes an amethyst tint with an excess of the standard solution. The titration with uranium acetate the author considers to be both difficult and uncertain.

The officially recognised rapid method for the determination of phosphorus in use in the United States is found by Messrs. S. W. Johnson and T. B. Osborne † to give results which are too high, and which are also irregular in the presence of iron and aluminium. The process referred to consists in precipitating the molybdate from the hot solution, which is digested for one hour at 65° C. The old Sonnenschein method is more accurate, as all the phosphate is precipitated with ammonia as the only base, no iron or aluminium being carried down. In this latter process the solutions are mixed in the cold, and are digested for six hours at or below 50° C.

III.—FUEL ANALYSIS.

The Determination of Sulphur in Coal.—W. Hempel ‡ presses the coal to be examined into a small cylinder in which a platinum wire has been laid. An ordinary glass bottle of a capacity of 10 litres is used as the combustion-chamber. This is closed with a three-bored indiarubber stopper. In this is a tube provided with a glass cock and expanded outside the stopper into a cylinder of about 50 cubic centimetres. Two other glass tubes also pass through the stopper, and these have at their lower ends two platinum wires fused into them, each

* *Gazzetta Chimica Italiana*, vol. xxii, pp. 117-123.

† *Annual Report of the Connecticut Agricultural Experimental Station*, 1890, pp. 195-197.

‡ *Zeitschrift für Angewandte Chemie*, 1892, p. 389, with illustration.

0.6 millimetre in thickness. One of these supports a small platinum wire cage. For the combustion a 6-cell Bunsen battery is used. The bottle is filled with oxygen, and the coal to be examined placed in the cylinder above referred to, which in turn is placed in the wire basket. It is then burnt, and after the combustion 100 cubic centimetres of water is charged into the flask, together with 5 cubic centimetres of hydrochloric acid and a little bromine. The whole is then allowed to stand for an hour at the least. The inside of the flask is then carefully washed down with the acid and afterwards with water, the solution being filtered into a beaker. It is then heated to boiling, and the sulphuric acid precipitated with barium chloride in the ordinary way. The results obtained by this method are higher than those obtained by that of Eschka.

F. Hundeshagen * observes that in determining sulphur in coal by the Eschka method, by heating with magnesia and sodium carbonate, a considerable loss of sulphur can be frequently observed in the form of ammonium sulphide or of sulphuretted hydrogen, which, escaping from the crucible, are lost to the determination. By replacing the sodium carbonate either altogether, or for the greater part, by potassium carbonate, this loss can be completely avoided.

Mr. J. O. Handy † gives his experience with this modified method. The results agree with those obtained by Eschka's method, over which there appears to be no improvement.

Van Leeuwen ‡ discusses the influence of the sulphur in the coal gas burnt, on the results of the determinations of sulphur by combustion. The Böckmann fusion mixture consists of one part of potassium chlorate with six of sodium carbonate. The author placed some of this mixture in a platinum dish provided with a porcelain cover, over which another porcelain dish was placed. When this was heated to fusion by gas there was always a considerable absorption of sulphur from the gas, and the author considers that a gas jet is not suitable for such determinations. An alcohol air jet burner is preferable. The author states that the gas he employed did not colour lead-acetate paper, and he concludes that the sulphur must have been present in it in the form of carbon disulphide.

* *Chemiker Zeitung*, vol. xvi. p. 1070.

† Paper read before the Engineers' Society of Western Pennsylvania, through the *Engineering and Mining Journal*, vol. liv. p. 408.

‡ *Recueil des travaux chimiques des Pays-bas*, 1892. p. 103.

STATISTICS.

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I.—UNITED KINGDOM.

Production of Pig Iron and Steel.—According to the returns of the British Iron Trade Association,* the production of Bessemer steel ingots in the United Kingdom during the first half of 1892 amounted to 649,816 tons, the production of acid and basic Bessemer steel ingots being respectively 544,399 and 105,417 tons.

The production of Bessemer steel rails during the same period amounted to 211,884 tons. There were $47\frac{1}{2}$ acid converters and $17\frac{1}{2}$ basic converters in operation.

The production of open-hearth steel ingots during the same period amounted to 722,341 tons, of which 661,237 tons consisted of acid ingots and 61,104 tons of basic ingots. There were $212\frac{1}{2}$ acid furnaces and 26 basic furnaces in operation.

The production of pig iron during the same period amounted to 2,790,918 tons.

The Cost of Production of Tin-Plate.—Mr. J. G. Carlisle† publishes the following statement of the cost of manufacturing tin-plate in the United Kingdom :—

* *Bulletin*, No. 17.

† *Iron Age*, vol. I. p. 292.

Average Prices.	1887.	Second Quarter 1891.
Coal, per ton	£ s. d. 0 5 6½	£ s. d. 0 8 11
No. 3 hematite pig iron, per ton	2 3 6½	2 9 1½
Bessemer bars, less 2½ per cent., per ton	4 10 6	5 9 0
	1 10 6	1 19 0
Acids, net, per ton	and 2 16 7½	and 3 2 6
Palm oil, net, per ton	20 8 1½	24 10 0
Tin (Straits), per ton	111 13 2	91 4 10
Lead, English common, per ton	12 16 4	12 13 3
Boxes, each	0 0 4	0 0 4½
Wages from bar to finished plate	0 2 3½	0 2 5½
Estimated actual cost, coke finish tin plate, standard 14 by 20 IC.	0 12 2½	0 13 1
Average selling price, do.	0 13 0	0 15 0
Shipments to United States, reduced to boxes, 14 by 20 IC, 12 months ending June 30	5,244,259	9,259,490

Details for the years 1888, 1889, and 1890 are also given.

II.—AUSTRALASIA.

Mineral Statistics of New South Wales.—The following table* shows the mineral production of New South Wales in 1891 as compared with 1890 :—

Description.	1891.	1890.
	Tons.	Tons.
Coal	4,037,920	3,060,876
Shale	40,349	56,010
Iron ore	4,125	3,413
Manganese ore	138	100
Pig iron	228	455
Limestone flux	74,037	41,436
Fireclay	16	..

Mineral Statistics of Victoria.—In the report † on the mining industry of Victoria, the output of coal for 1891 is given as 22,834 tons, and of lignite 6322 tons. Only one accident, and that non-fatal, occurred in the coal-mines. The number of men employed has increased by forty-nine and the output by 8000 tons.

Output of Coal in Queensland.—The production of coal in

* *Annual Report of the Department of Mines, New South Wales, for the Year 1891*, Sydney, 1892.

† *Annual Report of the Secretary for Mines, Melbourne, 1892*.

Queensland in 1891 was 271,603 tons, valued at £128,198. The decrease was mainly due to the decreased output of the Ipswich and Wide Bay districts.*

New Zealand, Imports and Exports.—In the year 1891 the imports and exports into and from New Zealand included † :—

	Imports.		Exports.	
	Tons.	Value, £	Tons.	Value, £
Coal	125,318	120,422	99,464	100,658
Hardware	—	130,130	—	4,343
Wire	6,951	73,276	5½	137
Rails	4,213	24,810	10½	56
Pig iron	3,816	15,531	7	54
Bar, bolt, and rod iron	4,567	41,195	42	384
Pipes	2,131	24,927	1½	21
Steel	1,185	15,012	15½	112
Iron ore	—	—	—	—
Manganese ore	—	—	1,153	2,634

III.—AUSTRIA-HUNGARY.

Iron Trade Statistics of Austria.—Recent official statistics † show that the quantity of iron ore raised in Austria in 1891 was 1,231,248 metric tons, a diminution of 9·57 per cent. as compared with the output in 1890. A diminution of over 34 per cent. was also shown in the case of manganese ore, only 5279 tons being produced. The quantity of asphalt raised showed practically no change, the output being in all 180 tons. On the other hand, there was an increase of 2·93 per cent. in the output of coal, and 5·57 in that of lignite, the total quantities raised being respectively 9,192,885 and 16,183,076 tons. No statistics are given of the output of the ores of chromium or nickel.

The forge pig iron made during the year amounted to 517,988 tons, a diminution of 9·87 per cent., and of foundry pig iron to 99,157 tons, an increase of 8·3 per cent. on the year. The production of iron ore and the outturn of pig iron was as follows in the various provinces :—

* *Iron*, vol. xl. p. 468.

† Official Statistics of the Colony of New Zealand for the year 1891, Wellington, 1892.

‡ *Statistisches Jahrbuch des K. K. Ackerbauministeriums*, 1892, Part I.; *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 395-397, 411.

Provinces	Iron Ore	Forge Pig Iron.	Foundry Pig Iron.	Total Pig Iron Output
	Tons.	Tons.	Tons.	Per cent.
Bohemia	313,320	109,701	17,573	20.62
Lower Austria	1,489	51,003	8,348	9.62
Salzburg	7,641	1,089	836	0.31
Moravia	21,635	134,062	58,563	31.21
Silesia	5,348	37,322	5,182	6.89
Styria	761,204	131,625	2,363	21.71
Carinthia	98,712	45,362	1,567	7.61
Tyrol	5,629	1,575	1,396	0.48
Carniola	7,454	6,250		1.01
Galicia	8,817	...	3,328	0.54
Totals	1,231,249	517,989	99,156	100.00

Details are given showing the increase or decrease in the several provinces as compared with the statistics for the previous year. The average price obtained for the ton of iron ore was 3s. 10d., for the ton of forge pig iron 66s. 3d., and 72s. for the ton of foundry pig iron.

The workpeople employed at the iron ore mines numbered 5506, and at the ironworks 10,493, diminutions of 245 and 348 respectively compared with the numbers employed during 1890. Lignite-mining gave employment to 42,924 workpeople, an increase of 3416 on the year, and coal-mining to 51,241 workpeople, an increase of 2493. The total quantity of coke made was 651,311 tons, from 1,069,821 tons of coal. As by-products, the Witkowitz works obtained 344 tons of ammonia, 260 tons of ammonium sulphate, and 1847 tons of tar. The production of briquettes from lignite amounted to 56,587 tons, and from coal to 21,319 tons. In making coal briquettes 21,061 tons of coal were mixed with 258 tons of tar. The total value of all the minerals raised and metallurgical products made in Austria, after subtracting the value of the ores smelted, amounted in 1891 to £7,752,420, an increase of 2.55 per cent. on the year. The total number of workpeople employed at the works and mines numbered 126,771, an increase of 5093 as compared with 1890. Of these 114,103 were employed in the mines and collieries.

Imports and Exports.—M. Caspaar * states that the iron trade imports and exports of Austria-Hungary in the year 1891 were as follows:—

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. p. 559.

Description.	Imports.	Exports.
	Tons.	Tons.
Lignite	15,174	6,900,255
Coal	3,670,196	714,435
Coke	248,193	73,453
Iron ore	68,121	88,059
Forge pig iron	4,889	7,395
Foundry pig iron	35,854	999
Bar iron and steel	7,938	9,088
Sheets	3,772	2,093
Castings, common	2,581	4,117
Total iron and iron manufactures	89,174	45,443
Firebricks and other similar material	3,275	4,759

Of the total imports 57 per cent. were from the German Customs Union, and 35 per cent. from the United Kingdom.

Accidents in Austrian Mines.—In 1891 there were in all 635 workpeople severely injured, the accidents proving fatal in 252 cases. The deaths amounted to 2·31 per thousand, and the severe accidents to 3·51 per thousand, of the total number of workpeople employed. In the collieries the fatal accidents numbered 130, an increase of 65 over 1890, and the severe ones 102, a similar increase of 6. In the lignite-mines 99 were killed and 230 injured, and in iron-ore mines 7 killed and 24 injured. The mineral raised was as follows :—

Mineral.	For each Fatal Accident.		For each Accident whether Fatal or otherwise.	
	1890.	1891.	1890.	1891.
	Tons.	Tons.	Tons.	Tons.
Coal	137,401	70,714	55,473	39,625
Lignite	141,936	163,465	53,786	49,189
Iron ore	226,925	175,893	52,367	39,718

It will thus be seen that there was a considerable increase in the number of accidents in 1891 as compared with the number which occurred in 1890. The accidents were mainly due to the following causes :—

	Per Cent. of Total.
Falls of roof, &c.	20·0
Accidents in hoisting	20·6
Firedamp explosions	10·4
Falls	8·0

The other causes of accidents in connection with which statistics are given include engines, machinery and tools, noxious gases, timbering, and blasting, whilst 21·4 per cent. of the accidents were due to causes not included under the heads mentioned. The most severe accident experienced during the year was an explosion of fire-damp on January 3, when sixty-one workmen lost their lives.*

The Output of Petroleum in Austria.—Of the 308 undertakings for raising petroleum in Austria in 1891, 199 were in operation, a diminution of 22 on the year. The workpeople employed numbered 3275, the production of petroleum amounting to 87,717 tons, a diminution of 4·29 per cent. compared with the output of 1890. Some new and very productive wells were sunk at Potok-Tarasowka, near Krosno, during the year; indeed, no such good results had previously been obtained in Galicia. Of ozokerite undertakings 79 were active, employing 6283 workpeople; these raised 6159 tons of the mineral, a diminution in the output as compared with that of 1890 of 10·48 per cent.†

The Iron Industry of the Tyrol.—In the Stubai valley, near Innsbruck, an iron industry has been carried on for centuries. It is confined to the manufacture of knives, tools, mountaineering appliances, and other small articles. The Stubai iron industry was active in the fourteenth century, but it attained its greatest development in the eighteenth century. At the present time it is unable to stand against the competition of modern steelworks. Raw material, too, is obtained with difficulty, as the iron-mines formerly existing in the valley have been worked out years ago, and a supply of charcoal is unavailable, as the forest has to be preserved as a guard against avalanches. According to the returns of the Chamber of Commerce of the North Tyrol, there are at the present time two ironworks with nine water-wheels and two turbines producing 140 horse-power, and numerous workmen carrying on their business in their own cottages, and owning twenty-three tilt-hammers with fifty-one water-wheels producing 300 horse-power. The production in 1890 amounted to 1295 cwt. of iron ware, 1080 cwt. of steel ware, and 940 cwt. of fine metal-work.‡

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. p. 522.

† *Ibid.*, p. 532.

‡ *Berg- und Hüttenmännische Zeitung*, vol. li. pp. 291-293.

Mining in Transylvania.—P. Weisz * gives an exhaustive description of the mining and metallurgical industries of Transylvania. The account of the various mines is accompanied by details of the geological structure of the district. The coal-beds described by the author are the following: (1) The Zsily lignite bed; (2) the Törcsvár-Feketehalm coal seam; (3) the lignite deposits in the vicinity of Baróth; (4) the lignite beds in the Egeres district; (5) the lignite beds in the vicinity of Borszék; (6) the lignite beds in the Szurdok region; and (7) the lignite deposits in the Valebrád-Meszteakon districts. The iron mines and works described by the author are the following: (1) The Vajda-Hunyad-Gorasiaer Government Ironworks; (2) the Kúdsir iron and steel refinery; (3) the Telek iron-mines and the Pusztá-Kalán iron-works; (4) the Rojáhida iron-mines; (5) the Szentkerestbánya iron-works; and (6) the Füle and Magyar-Hermány iron mines and works.

Wages in the Bohemian Collieries.—According to official reports,† the mean daily wages paid to miners in the Bohemian brown-coal mines are as follows:—

Mining District.	Coal-getters.		Putters.		Surface Workmen.		Women.	
	s.	d.	s.	d.	s.	d.	s.	d.
Teplitz	3	2½	2	3½	1	10½	1	2½
Brux	3	7½	2	1½	1	11	1	2
Falkenau	2	3½	2	0½	1	7½	1	0½
Ellbogen	2	5½	2	2½	1	8	1	1
Kommatau	2	6½	2	0½	1	7½	1	0

The overmen receive on an average 3s. 4d. per day in the Teplitz and Brux districts, 2s. 8½d. in the Falkenau district, 2s. 8d. in the Ellbogen district, and 2s. 9d. in the Kommatau district.

The Bohemian brown-coal miners are paid higher wages than any other miners in Austria, the mean daily wages paid in the Bohemian bituminous mines being as follows:—

Mining District.	Coal-getters.		Putters.		Surface Workmen.		Women.	
	s.	d.	s.	d.	s.	d.	s.	d.
Prague	2	5	1	5	1	2	0	8½
Schläu	2	8	1	10	1	3	1	0
Pilsen	2	5	1	8½	1	3½	0	10½
Mies	2	9	1	8	1	4	0	9½

* *Mittheilungen aus dem Jahrbuch der Königlich Geologischen Anstalt*, vol. ix. pp. 105-184.

† *Berg- und Hüttenmännische Zeitung*, vol. li. p. 263.

The average annual wages of the Bohemian brown-coal miners in 1891 amounted to £42, 2s. 3d.

IV.—BELGIUM.

Pig Iron.—The production of pig iron in Belgium * during the first half of 1892, as compared with that for the corresponding period of the previous year, was as follows :—

Description.	First Half.	
	1892.	1891.
	Tons.	Tons.
Forge pig iron	236,600	195,810
Foundry pig iron	28,640	23,295
Bessemer pig iron.	99,790	75,056
Totals	365,030	294,161

Imports and Exports.—The imports and exports of Belgium † during the first six months of 1892, compared with the corresponding period of 1891, were as follows :—

Description.	Imports.		Exports.	
	First Half, 1892.	First Half, 1891.	First Half, 1892.	First Half, 1891.
	Tons.	Tons.	Tons.	Tons.
Crude cast steel	2,987	4,207	808	761
Steel rails	486	749	33,041	24,009
Other steel	3,723	1,717	6,170	3,787
Finished steel	789	716	4,610	2,939
Pig iron	68,779	82,194	8,153	7,072
Scrap iron	11,837	10,884	5,069	4,449
Iron wire	2,462	2,481	939	1,099
Iron rails	29	49	8,758	8,256
Iron plates	531	832	25,591	21,144
Iron, miscellaneous	5,246	5,292	84,504	96,622
Nails	334	343	3,081	3,948
Wrought iron	2,125	2,013	11,737	13,008
Castings	349	892	11,413	14,092
Rolling stock	881	1,264	22,403	13,570
Machinery	7,153	7,986	17,557	15,804
Totals	107,711	121,619	243,834	230,560

* *Iron*, vol. xl. p. 60.

† *Ibid.*, p. 106.

Description.	Imports.		Exports.	
	First Half, 1892.	First Half, 1891.	First Half, 1892.	First Half, 1891.
Iron ore	Tons. 859,062	Tons. 744,297	Tons. 124,336	Tons. 83,331
Coal	710,691	796,739	1,083,724	2,074,946
Coke	94,783	60,775	473,660	482,818

V.—CANADA.

Mineral Statistics of Ontario.—According to the first report of the Bureau of Mines, iron-mining in Ontario was of a prospective character only, the total quantity of iron ore raised being about 200 tons. Explorations made with the diamond-drill in the township of Belmont, and on the Mattawan and Atik-Okan rivers, are claimed to have demonstrated the existence of large bodies of excellent ore in those localities.

The total output of crude petroleum in Ontario in 1891 amounted to 894,647 barrels, valued at 1,209,558 dollars.

The product of eight nickel-mines was 85,790 tons, returned at the low valuation of 324,240 dollars. The total amount paid for labour was 322,201 dollars. These returns of course do not include labour for roasting and smelting the ore, nor its value when converted into matte. Of the latter product in 1891 the United States Government purchased for armour-plate purposes 4536 tons, containing about 900 tons of nickel.

Iron-Making in Nova Scotia.—The advancement of the iron industry in Nova Scotia during 1892 has afforded a striking contrast to the general dulness in mining matters. The successful blowing-in of the New Glasgow Company's furnace at Ferrona in Pictou County is announced. The operations of the company have disclosed large veins of brown hæmatite, from which 400 tons of ore can be raised daily. Their fluxes are quarried in the immediate vicinity of the iron ore.

The Pictou Charcoal Iron Company has acquired several deposits of excellent brown hæmatite ore on the line of the new railway, and is entering upon the manufacture of charcoal iron. At Torbrook in Annapolis Valley the iron ore mined is of excellent quality, and has been smelted at the Londonderry furnaces. It is also contemplated reopening the Clementsport mines. These facts warrant the hope that the iron industry of Nova Scotia is beginning to grow steadily if slowly.*

VI.—CHILI.

Manganese Ore.—There are two manganese ore districts in Chili, those of Coquimbo and Carrizal, the latter being also known by the name of Huasco. The Coquimbo ore-field is close to the port of that name. The mining district proper is known as Chanar Quemada, and is in the province of Atacama. Ore was first mined in this district in 1886, the Coquimbo district being some years the older of the two. These districts have produced :—

Years.	Coquimbo,	Carrizal,
	Tons.	Tons.
1885	4,041	...
1886	23,701	227
1887	38,234	9,287
1888	12,132	6,581
1889	9,145	19,538
1890	23,409	24,577
1891	16,462	18,000

The total production of manganese ore in Chili in 1891 was thus about 34,500 tons.†

VII.—FRANCE.

Iron and Steel.—The production of iron and steel during the first halves of 1892 and of 1891 was as follows :—‡

* *Canadian Mining Review*, vol. xi. p. 151.

† *American Manufacturer*, vol. li. p. 59.

‡ *La Metallurgie*, 1892, pp. 1451-1452.

Description.	First Half, 1892.	First Half, 1891.
	Metric Tons.	Metric Tons.
Forge pig iron	826,953	765,057
Foundry pig iron	190,109	206,266
Totals	1,017,062	971,323
Wrought iron, rails	244	244
" " merchant	361,673	339,632
" " plates	62,048	56,715
Totals	423,965	396,591
Steel, rails	119,319	93,133
" merchant	153,313	148,941
" plates	59,307	51,993
Totals	331,939	294,067
Total iron and steel	755,904	690,658

Coal.—The total output of coal in France in 1891 amounted to 26,327,000 tons, about 2,000,000 tons in excess of the output of the previous year. From the coalfields of the Pas-de-Calais the output reached 9,076,579 tons, 31,000 workpeople were employed, and the accidents numbered 114, involving fatal injuries to 35, and lesser ones to 121 workpeople. The deaths amounted to one per 256,000 tons of coal raised. The other departments raised as follows: Nord, 5,201,000 tons; Loire, 3,532,000 tons; Gard, 2,030,000 tons; Saône et Loire, 1,714,000 tons; and Allier, 1,002,000 tons.*

Imports and Exports.—The following table shows the French imports and exports during the first six months of 1892 as compared with the corresponding period of 1891 †:—

Description.	Imports.		Exports.	
	First Half, 1892.	First Half, 1891.	First Half, 1892.	First Half, 1891.
	Tons.	Tons.	Tons.	Tons.
Coke	649,500	620,552	18,247	25,149
Iron ore	779,700	620,103	145,539	127,676
Crude iron of all classes	41,925	28,496	52,641	37,198
Manufactured iron	6,724	6,702	13,317	15,702
Steel	3,575	2,181	4,166	12,818
Total iron and steel	52,224	37,381	70,124	65,718

* *Mining Journal*, vol. lxi. p. 1224.

† *Iron*, vol. xl. p. 106.

The temporary imports and exports during the same period were as follows :—

Description.	Imports.		Exports.	
	First Half, 1892.	First Half, 1891.	First Half, 1892.	First Half, 1891.
	Tons.	Tons.	Tons.	Tons.
Forge pig iron	14,845	29,938	12,364	19,750
Foundry pig iron	14,408	18,649	13,426	21,307
Manufactured iron	11,799	9,783	9,754	7,538
Steel	877	1,242	928	1,461
Totals	41,929	59,612	36,472	50,056

VIII.—GERMANY.

Mineral Statistics.—According to the official statistics * for the German Empire for 1891 the production of iron ore amounted to 10,657,520 tons from 681 mines, employing altogether 35,390 workmen.

The production of pig iron was 4,641,217 tons from 109 ironworks, employing altogether 24,773 workmen. There were 218 furnaces in blast.

Finished iron was made at 250 works, 69,111 tons of blooms being produced, and 49,596 workmen employed. The total make of partially and fully manufactured iron amounted to 1,484,064 tons.

Steel was made at 117 works, 57,929 workmen being employed. The total production of partially manufactured steel was 721,486 tons, and the total production of manufactured steel was 1,841,063 tons.

Production of Pig Iron.—During the first six months of 1892 the production of pig iron in Germany was as follows † :—

	Metric Tons.
Forge pig iron and spiegeleisen	940,842
Foundry pig iron	300,860
Acid Bessemer pig iron	171,323
Basic Bessemer pig iron	983,102
	<hr/> 2,396,127

During the first half of the previous year this total was 2,123,466.

* *British Iron Trade Association, Bulletin*, No. 20.

† Compiled from the monthly reports appearing in *Stahl und Eisen*.

Iron-Ore Mining in the Siegen District.—The iron ore mined in this district in the year 1891 amounted to 1,473,185 tons of the value of £574,542 as compared with 1,523,573 tons valued at £860,818 in the previous year. The average price at which the ton of spathic ore sold was 7s. 8½d. at the mine, a reduction of 3s. 6d. when compared with the price obtained in 1890. The workpeople employed in 1891 in iron-ore mining numbered 12,140 as compared with 12,466 in 1890, the output of ore per workman employed being respectively 121·35 and 122·28 tons in the years mentioned. Of the thirty-four existing coke blast furnaces twenty-nine were in blast in 1891, twenty-one of which were continually in blast throughout the year, and these twenty-nine furnaces produced 501,711 tons of pig iron, an increase of 5·37 per cent. on the output of the year 1890. The workpeople employed at the blast furnaces in 1891 numbered 2163. The use of ingot metal for plates is seriously affecting the Siegen iron trade.*

The Dortmund Mining District.—In a report on the Dortmund mining district and on that of the Lower Rhine and Westphalia, M. Reuss † gives the following details relating to the output of coal, and to the value of such output in these districts :—

Year.	Output.	Value.	Number of Collieries.	Workpeople Employed.
	Tons.	£		
1792	176,676	34,183	154	1,357
1800	230,558	519,507	158	1,546
1820	425,369	113,957	177	3,117
1840	990,352	319,817	221	8,945
1850	1,665,662	519,254	198	12,741
1860	4,365,834	1,402,751	281	29,320
1870	11,812,528	3,381,302	220	51,391
1880	22,495,204	5,147,693	202	80,152
1890	37,402,494	15,638,997	175	138,739

Within a single century, therefore, the production of coal has become 200 times as great as it was, while the value of the output is now 457 times what it was a century ago.

Mineral Statistics of Upper Silesia.—Dr. H. Voltz † publishes the iron-trade statistics relating to Upper Silesia for the year 1891. As in 1890, so in 1891, there were 56 active collieries. The work-

* *Stahl und Eisen*, vol. xii. p. 718.

† *Ibid.*, p. 673.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 262-265, and 271-274.

people these employed numbered 54,746, an increase of over 10 per cent. on the year. The average annual wages per workman amounted to £41, 1s. Within the past five years the wages have increased by as much as 28·7 per cent. The output of coal reached 17,730,362 tons, an increase of 5·14 per cent.

The statistics collected in 1891 relating to iron-ore mines show these to number 56, as compared with 62 in 1890. They employed 3977 workpeople, each workman employed earning £27, 4s. during the year. The iron ore raised amounted to 654,537 tons, as compared with 769,742 tons in 1890. The average quantity of ore raised per workman employed was 164·5 tons, as compared with 176·8 in 1890.

The active ironworks numbered 11 both in 1891 and in 1890. The coke furnaces in blast in 1891 were 30, an increase of 1 on the year, and these gave employment to 4147 workpeople. The average annual wages of a workman was £38, 3s. The materials smelted included 917,064 tons of iron ore, 454,305 tons of limestone, and 775,459 tons of coal and coke. The pig iron produced amounted to 478,605 tons, as compared with 507,293 tons in 1890. The fuel used per ton of pig iron made was 1·620 ton. The forge pig iron made amounted to 61·21 of the total quantity, but it was 14·3 per cent. less than the quantity made in 1890. Foundry pig iron showed, on the other hand, an increase of 8·6 per cent. on the total quantity made during 1890, while acid Bessemer pig iron was 52·8 per cent. less, and basic pig iron 18 per cent. more than the corresponding metal made in the year referred to. Of charcoal blast furnaces two are mentioned, but only one was in blast, the production during a period of 51½ weeks being but 1201 tons, the outturn in 1890 having been slightly less—1018 tons. For each ton of charcoal pig iron made there was charged 3·47 tons of ore, 0·3 ton of limestone, and 1·5 ton of charcoal. The average value of the ton of metal made was £5.

There were 25 foundries active in 1891, and these had in operation 36 cupolas, 12 reverberatory furnaces of various kinds, and 3 open-hearths. The workpeople employed numbered 1819, the average wages per workman being £38, 11s. The castings made weighed 37,232 tons. Of this quantity 7398 tons were pipes. The production was 2 per cent. more in 1890 than in 1891.

The works making weld and ingot iron numbered 21, the same as in 1890. Fourteen of these made weld iron. These 14 works possessed 263 puddling furnaces and 212 furnaces of other kinds, together with 59 steam-hammers. In the manufacture of ingot iron

there were employed 8 cupolas, 1 acid Bessemer converter and 5 basic ones, 16 basic and 3 acid-lined open-hearths, 31 other furnaces, and 15 steam-hammers. The trains of rolls numbered 83. The workmen employed numbered 12,487 and the women 625. The average wages of a workman (over 16 years of age) was £39, 6s. In the manufacture of weld iron there was used 466,402 tons of pig iron, 118,655 tons of other iron, and 658 tons of iron ore. In that of ingot metal there was used 180,968 tons of pig iron, and 69,060 tons of scrap. The fuel used was 898,393 tons. The total outturn was 415,018 tons in 1891, that of 1890 having been 387,290 tons. In addition 39,123 tons of wire, wire rods, nails, springs, and tubes, were also made. Of coke ovens the following systems were in use:—Appolt, Beehive, Collin, Coppée, Dilla, Dulait, Essenöfen, Fritsch, Gobiet, Königshütte, Otto, Schaumburg, Siemens, Smet, Wintzek, and the ordinary Welsh oven. The workpeople employed numbered 2554. The production of lump coke was 902,202 tons, and of coke smalls 86,455 tons, 1,604,705 tons of coal being used.

Mineral Statistics of Saxony.—According to the official statistics,* the production of coal in the kingdom of Saxony, in the year 1891, amounted to 4,366,819 tons, and that of lignite to 864,376 tons, the output per miner being 207·81 tons in the collieries and 380·95 tons in the lignite mines. The production of iron ore amounted to 14,158 tons, valued at £7382, and that of manganese ore to 2045 tons, valued at £943.

Mineral Statistics of Bavaria.—The quantity of coal raised in Bavaria in 1891 amounted to 756,148 tons, and of lignite to 10,044 tons. Of iron ores 149,653 tons was raised, as well as 260 tons of manganese ore. The collieries at work numbered twenty-three, employing 13,809 workpeople; the active lignite mines nine, employing 342 workpeople, and the active iron ore mines thirty-eight, employing 673 men and 1377 women and children. The manganese ore came from two mines, with six workpeople. The average value of the ton of coal, lignite, iron ore, and manganese ore was respectively 10s. 7d., 4s. 7d., 4s., and 10s. Of graphite 3824 tons, valued at £3, 17s. per ton, was raised; and of fire-clay 103,287 tons, valued at 7s. 9d. per ton.

Pig iron was made at three works, the output being 76,552 tons,

* *Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen*, 1892. pp. 1-185.

and 52,470 tons of castings was made at seventy-one foundries. Nineteen works made 64,743 tons of bar iron, one works made 1644 tons of wire, and 2 others 282 tons of black sheets. There were four active steelworks, the outturn of which amounted to 67,088 tons.*

The History of the Königshuld Ironworks.—H. Fechner † has compiled, from the records of the State archives at Breslau, a history of the foundation of the Königshuld Ironworks in Upper Silesia. The works present one of the best monuments of the care exercised by Frederick the Great for advancing the industries of his domains. Called into existence in the face of great difficulties, the works taught methods of procedure that were subsequently followed by numerous other establishments. The Königshuld Works were founded on November 27, 1789. In 1790 the products of these works were sent to Danzig and other Baltic ports, and orders were received even from the celebrated Dutton's works in Berlin. The events of 1806 rendered the support of the Government impossible. The works, however, continued to exist. In 1888, with the aid of 100 workmen, cutlery was manufactured to the value of £20,000.

IX.—INDIA.

Coal.—The total yield of coal in India is given as 2,045,000 tons in 1889, and 2,168,000 tons in 1890. The imports were 605,000 tons in 1889, and 784,000 tons in 1890. The bulk of this came from England, but Japan sent 12,014 tons, and Australia 10,017 tons.‡

X.—ITALY.

Mineral Statistics.—Italy does not possess very large deposits of iron ore, and coal is scarce. The iron ore that is produced is, however, of good quality. Unfortunately, the ore deposits seem to be becoming exhausted, and the production consequently more expensive. The first export of iron ore to Great Britain was 119 tons in 1870. This rose to 47,500 tons in 1872, and attained a maximum of

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 450–451.

† *Zeitschrift für das Berg- Hütten- und Salinenwesen im Preussischen Staate*, vol. xl. pp. 279–288.

‡ *Engineering and Mining Journal*, vol. liv. p. 341.

86,301 tons in 1887, the ores ranging from 61 to 66 per cent. of iron. Of recent years the exports have, however, fallen off, and the total production has fallen from 421,000 tons in 1881 to about 200,000 tons per annum. The workmen employed in 1881 numbered 2245, as compared with 2434 in 1890. In the latter year the production of iron ore and fuel was as follows in the districts named below :—

Districts.	Iron Ore.	Coal and Lignite.
	Tons.	Tons.
Florence	189,752	203,004
Iglesias	—	15,701
Milan	28,750	3,000
Rome	—	127,790
Turin	2,200	591
Vicenza	—	26,240

The output of fuel is supplemented by large imports, principally from England and Germany, but the consumption per head is very low, and fuel is dear. The following table gives the production of minerals for the whole country * :—

Description.	Production.	Number of Mines.	Number of Workmen.
	Tons.		
Iron ore	220,702	44	2434
Manganese ore	2,147	4	89
Coal and lignite	376,326	38	2817
Asphalt and bitumen	45,125	20	729
Graphite	1,735	9	47

The greater part of the iron produced is in the form of bar iron, but hoop iron is made in a few instances—notably at Belluno, where it is the main product. Direct and cement steel are made in a few works on a small scale. Genoa is the largest steel-producing province, the output in 1890 being 57,450 tons. The Terni works, near Rome, produced only 46,666 tons, chiefly in the form of rails. Bessemer steel is only made at one works, and the make did not exceed 200 tons. Water-power is largely used, the hydraulic motors numbering 754, with a power of 16,110 horse-power, as compared with 86 steam-engines of 10,048 horse-power.

The maximum output of both finished iron and steel was attained in 1889, when the production was 181,623 and 157,899 tons respectively. In 1890 the production of steel declined by as much as 50,000 tons.

* *Engineering*, vol. liv., pp. 728 729.

The quantity made in 1885 was only 6370 tons of steel. The number of works officially recorded in 1890 as producing iron and steel was 325, employing 13,799 workmen, and the total outturn of these metals was 283,300 tons.

Mineral Statistics of Sardinia.—According to a recent report the number of mines in Sardinia, with their output, was as follows in the year 1890-91 * :—

Description.	Number of Mines.	Quantity.	Value.
		Tons.	£
Manganese ore	1	1,600	1,423
Iron ore	1	10,190	4,076
Lignite	4	14,199	6,652

XI.—JAPAN.

Japanese Coal.—Mr. J. C. Hall, H.M. Consul at Hakodate, in his trade report for the year 1891, refers to the coal-deposits of the Island of Yezo. Fifteen years ago it was estimated by the American engineers, who made the first surveys for the Government, that the workable coal-beds in Japan contained 150,000,000,000 tons, or about two-thirds as much as the coal-beds of Great Britain. Doubts have sometimes been expressed as to the soundness of this large estimate, but time and further investigation have confirmed it. An elaborate Japanese report embodying the results of the most recent surveys, was published in March 1891. From this official document it appears that there are in the workable seams of Yezo 600,000,000 tons of coal, the total for the rest of Japan being 700,000,000 tons. Of the Yezo coal, nine-tenths is found in one district, that of the valley of the Ishikari River, near the west coast; the remaining tenth being scattered over five fields, of which the most important, that called Rumoe, in the province of Teshiwo, lies quite close to the coast on the same side of the island, just north of the head waters of the Ishikari River. Then come the Soya coalfield, at the extreme north of the island, and the Kushiro, on the south-east coast, each containing 10,000,000 tons. The first coal mined in the island, at Iwanai in the province of Shiribeshi, belongs

* *Industries*, vol. xiii. p. 180. See also a paper by E. de Launay, *Annales des mines*, vol. i. pp. 511-538.

to the smallest of the six coalfields, containing barely 2,000,000 tons. As regards the quality of this mineral, although it is very irregular, and none of it stands in the front rank, even of Japanese coal, still it is all marketable, and some of the better-class mines in the Ishikari field, notably those of Horonai, Ikushumbetsu, and Sorachi, yield a coal not at all inferior to the product of the Kiushiu mines, the famous and fast-dwindling Takashima alone excepted. Though found in comparatively recent geological strata, they are true bituminous coals, widely removed by their composition from all known coals of similar age, and equal in commercial value to Australian coal.

XII.—RUSSIA.

Mineral Statistics.—The production of pig iron in Russia in 1891 is estimated * at 936,000 tons (exclusive of the production of Finland). The increase in the iron industry since 1887 has been very considerable, for in that year the production did not exceed 601,000 tons.

The production † of iron ore in Russia in 1890 amounted to 1,768,097 tons from 581 mines and 195 lakes. The production of manganese ore was 179,672 tons from 300 mines, and that of chrome iron ore was 2333 tons.

The production of pig iron in 1890 was as follows :—

	Tons.
Charcoal pig iron	602,074
Coke pig iron	294,812
Mixed fuel pig iron	15,404
Total	912,290

There was 146 ironworks, with 69 cold-blast and 145 hot-blast furnaces in operation.

The production of weld iron was 482,537 tons, and that of steel 372,625 tons.

Coal-Mining in Poland.—An exhaustive account has recently been published ‡ of coal-mining in Poland. The industry was first started at the end of the last century, but made little progress until 1816, when the output was under 4000 tons. By 1825 it reached nearly 60,000 tons, but fell to about 9000 tons in 1831. The Bank of

* *Berg- und Hüttenmännische Zeitung*, vol. li. p. 383.

† *Gorny listok*, 15th October 1892; *British Iron Trade Association, Bulletin*, No. 19.

‡ *Viestnik Financov*, St. Petersburg, through *Iron*, vol. xl p. 164-165.

Poland then took command with success until 1843, when the Department of Finance assumed the management. The state of the industry fluctuated considerably, but a stimulus was given by the law of 1870, which controlled mineral rights apart from the soil. At the present time most of the coal is produced by four or five counties, the total output last year amounting to 2,553,000 tons. The number of people employed is given as 11,294 for 1891.

The Iron Industry of Finland.—According to the most recent official statistics* there existed in the Wiborg district in 1889 only one active iron-ore mine. This had an output of 1030 tons. On the other hand, 47,663 tons of lake iron ore was raised from 169 lakes. In fourteen blast furnaces 15,060 tons of pig iron was made. For each 100 kilogrammes of iron ore there was used, 0·37 hectolitres of wood for drying, and 7·37 hectolitres for smelting. The blast had a temperature of about 200° C., except in four cases where cold blast was used. The lake ore averaged 35 per cent. of iron, and Swedish ore also smelted contained from 50 to 54 per cent. of metal. In hearths 3558 tons of malleable iron was made, each hearth making as a daily average 0·77 ton of metal and using 64½ hectolitres of charcoal, with a loss of 16 per cent. of the pig iron used. Puddling was carried on at seven works. These made 9305 tons of iron, with a loss of 12 per cent., the daily average for each furnace being 2·5 tons. The rolling-mills treated only Finnish metal, their outturn amounting to 6560 tons. Ingot iron was made almost solely at Aminnefors, where open-hearth furnaces are in use. Here there was made 846 tons of ingots from 862 tons of pig iron, 0·3 ton of ferro-silicon, and 1·7 ton of ferro-manganese. A second works made 150 tons. The loss in rolling reached 18·7 per cent. The manufactures amounted to 3227 tons, mostly nails. The twenty-four foundries made together 4689 tons of castings. The whole of the manufacturing establishments in Finland treated in 1889, 682 tons of pig iron, 1728 tons of weld iron, and 2652 tons of steel.

XIII.—SPAIN.

Imports and Exports.—The imports for the first half of 1892, as compared with those for the corresponding period in the previous year, were as follows†:—

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. p. 160.

† *Iron*, vol. xl. p. 148.

Description.	First Half, 1892.	First Half, 1891.
	Tons.	Tons.
Coal	812,989	881,788
Coke	76,251	143,105
Pig iron	18,442	11,432
Castings	5,880	9,839
Bars and steel rails	21,673	18,237
Tin-plates	2,189	1,029

The exports were—

Description.	First Half, 1892.	First Half, 1891.
	Tons.	Tons.
Iron ore	2,399,721	2,198,789
Iron	23,808	26,940

The School of Mines at Madrid.—The Spanish Government has recently devoted much attention to the equipment of a suitable mining school. At present the attendance of students is but small. The school itself appears to have an important future before it in view of the well-known mineral richness of the country. F. Toldt * describes the course of teaching adopted. The Government devoted £40,000 to the erection of the buildings and to their contents. The course is of three years' duration. During the first year the studies include chemistry and assaying, mineralogy, and mechanics; during the second, geology and palæontology, civil engineering, and metallurgy; and during the third year, mining, metallurgy, and electro-technology. The students must pass through the ordinary course at the polytechnic school before entering the School of Mines. Excursions are made by the students as a part of their course of studies, similar to the mining and metallurgical excursions of the students at the Royal School of Mines in London.

XIV.—SWEDEN.

Mineral Statistics.—According to the official statistics in Sweden in 1890, 940,429 tons of iron ore was raised from 390 mines, and at

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. p. 446.

three places in the south of the country 812 tons of lake ore was obtained.

The production of pig iron amounted to 541,442 tons, besides 4659 tons of raw castings. There were 154 furnaces in blast for 37891½ days, each furnace producing 2961 tons and being in blast for 246 days.

There were 119 foundries in operation, yielding 32,969 tons of castings.

At 99 works 225,631 tons of blooms was produced, and at 157 works, with 445 furnaces, 281,832 tons of bar iron was also made. This total includes 317 tons of Uchatius metal.

Ingot iron and steel were obtained at 45 works, the production amounting to 169,287 tons. Of this total, 94,247 tons was made at 14 Bessemer works, 72,984 tons at 22 open-hearth works, and 2055 tons at 9 other works (including 431 tons of Uchatius steel).

Manufactured iron and steel were made at 153 works, the total product of 78,997 tons consisting of 28,928 tons of plates, 12,142 tons of nails, 10,105 tons of rails, 6118 tons of tools, and 21,704 tons of other articles.

The production of manganese ore amounted to 10,698 tons. The production of coal was almost the same as in 1890; it amounted to 2,343,895 hectolitres. The production of fireclay amounted to 978,355 hectolitres.*

XV.—UNITED STATES.

Iron Trade Statistics.—According to the report of the American Iron and Steel Association, the production of pig iron during the first half of 1892 was as follows:—

	Tons.
Charcoal pig iron	279,915
Coke pig iron	3,587,442
Anthracite pig iron	931,699
Total	4,799,056

Of the production in the first half of 1892 the amount within the Bessemer limit was 2,268,608 tons. The outturn of pig iron during the first half of 1891 amounted to 4,911,763 tons.

Production of Bessemer Steel.—The production of Bessemer

* *Kommersse kollegii berättelse för år 1890, Stockholm, 1892.*

steel ingots and rails in the United States was as follows in the first half of 1892, the figures for the same period of the previous year being given for comparison :—

Material.	First Half, 1892.	First Half, 1891.
	Tons of 2000 lbs.	Tons of 2000 lbs.
Ingots	2,305,909	1,599,096
Rails	865,128	579,929

The production of Clapp-Griffiths steel, included in the above, was 41,411 tons in the first half of 1892, and 33,789 in that of 1891.*

Production of Iron Ore.—In his exhaustive report on the production of iron ore in the United States, Mr. J. Birkinbine† estimates the total quantity produced in 1890 at 16,036,043 tons. This total, however, does not represent all the material used as iron ores. Many of the blast furnaces employ, as part of the charge, cinder from puddling and heating furnaces, or the residue from burning pyrites for the production of sulphuric acid. The residue containing iron and manganese resulting from the treatment of the New Jersey franklinite is also utilised in several blast furnaces to produce spiegeleisen. The quantity of such material used in 1890 is estimated at 850,000 tons.

The production of the different classes of ore in 1890 was as follows :—

	Tons.	Per Cent.
Red hæmatite	10,527,650	65·65
Brown hæmatite	2,559,938	15·96
Magnetite	2,370,838	16·03
Spathic ore	377,617	2·36
Total	16,036,043	100·00

Of this total 44·54 per cent. was produced by Michigan, and 11·83 per cent. by Alabama.

Full details are given in the report concerning the iron ores of the various States.

Condition of the Blast Furnaces.—At July 1, 1892, the furnaces in blast in the United States‡ numbered 254, with a weekly capacity

* *American Manufacturer*, vol. li. p. 276.

† *Mineral Resources of the United States. Calendar Years 1889 and 1890.* Washington, 1892, pp. 23-47.

‡ *Iron Age*, vol. i. p. 69.

of 169,151 tons. Classified according to the fuel used, the furnaces were as follows :—

	Charcoal.	Anthracite.	Coke.
Number of furnaces	122	159	256
Number in blast	42	72	140
Capacity per week	9,964	31,754	127,433

Production of Tin and Terne Plates.—The official return shows that during the fiscal year ending June 30, 1892, the production of tin and terne plates in the United States amounted to 13,496,521 lbs. How rapid the progress of this industry has been will be seen from the outputs during each of the four quarters of the fiscal year :—

Quarter ending	Output, lbs.
September 30, 1891	826,922
December 31, 1891	1,409,821
March 31, 1892	3,004,087
June 30, 1892	8,255,691

Of the output during the June quarter, over 5,000,000 lbs. was made from American black plates.*

The Wages Paid in United States Foundries.—A tabular statement is published in the *Iron Age* † showing the wages paid to workpeople in United States foundries. The foundries to which the statements refer are seventy-eight in number, and the wages are based upon a day of ten hours. The wages paid are as follows :—

	Dollars.	Average. Dollars.
Moulders	1.25 to 4.50	2.50
Core-makers	1.10 „ 3.75	2.00
Cupola-tenders	1.10 „ 3.00	1.75
Chippers	1.00 „ 2.75	1.50

The averages are merely approximations.

Imports of Iron and Steel.—The following table ‡ from the monthly summary of the Bureau of Statistics, shows the imports into the United States during the fiscal year ending June 30, 1892 :—

* *Iron Age*, vol. I. p. 350.

† *Ibid.*, vol. xlix. p. 1038.

‡ *British Iron Trade Association, Bulletin*, No. 17.

Articles.	Tons.
Pig iron	82,891
Scrap iron and steel	33,769
Bar iron	20,829
Iron and steel rails	299
Cotton-ties, hoops, &c.	473
Hoop, band, or scroll iron or steel	1,090
Steel ingots, blooms, billets, &c.	36,412
Sheet, plate, and taggers iron or steel	14,486
Tin-plates	186,686
Wire rods, iron or steel	43,353
Wire and wire rope, iron or steel	3,514
Anvils	805
Chains	463
Total	430,070
Iron ore	1,003,887

Exports of Petroleum.—The total exports of petroleum, including raw and refined oil and naphtha, from the United States during the first half of 1892 amounted to 333,394,844 gallons, as compared with 283,745,078 gallons exported during the same period of 1891.*

XVI.—COMPARATIVE TABLES.

The World's Production of Coal and Iron.—For purposes of comparison the following summary of the production of coal in the principal countries of the world is appended :—

Country.	Year.	Production in Tons.
United Kingdom	1891	185,479,126
Australasia—		
New South Wales	1891	4,037,920
New Zealand	1891	668,794
Queensland	1891	271,603
Victoria	1891	22,834
Tasmania	1890	58,812
Austria, coal	1891	9,192,885
" lignite	1891	16,183,076
Hungary, coal	1891	994,812
" lignite	1890	2,249,098
Belgium	1891	19,865,345
Cape of Good Hope	1890	33,021
Canada	1891	3,400,479
France	1891	26,327,000
Germany, coal	1890	70,237,808
" lignite	1890	19,053,026
India	1890	2,168,000
Italy, lignite	1891	289,286
Japan	1887	1,492,000
Natal	1890	65,188
Russia	1890	6,113,560
Spain	1891	1,286,000
Sweden	1889	256,628
United States	1890	141,229,513

* *American Manufacturer*, vol. II. p. 78.

A similar summary showing the production of pig iron is as follows:—

Country.	Year.	Production in Tons.
United Kingdom	1891	7,228,496
Austria	1891	617,145
Hungary	1890	285,102
Belgium	1891	688,056
Canada	1891	23,891
France	1891	1,919,185
Germany	1891	4,641,217
Italy	1891	11,930
Russia	1891	936,000
Spain	1891	278,462
Sweden	1890	541,442
United States	1891	8,279,870

Production and Export of Iron and Steel.—Mr. W. Jacks* discusses the comparative progress of the iron and steel industries of different countries in reference to production and exports, and the lessons to be learned therefrom. The exports of Germany have increased, while those of Britain and Belgium have been reduced. Prices everywhere have diminished. In Germany the ores and labour are cheap, but coke rates are higher than in this country. Between 1870 and 1890 the percentage productions have varied as follows in the following countries:—

Countries.	Pig Iron.		Finished Iron.		Bessemer Steel.	
	1870.	1890.	1870.	1890.	1870.	1890.
Great Britain	58	32	43	26	45	23
Germany	11	19	15	20	—	—
United States	16	37	22	37	9	50

The decline in British production and exports appears to be chiefly due to the lessened demand from America, but the competition of Germany appears to threaten the greatest danger. In seeking for explanations of the facts, the author refers to the number and severity of the strikes, and to the heaviness of the royalties imposed. Conciliation boards to improve the relations between employers and labour are called for, and also greater attention of our foreign diplomatists to the commercial interests of this country.

* Paper read before the British Iron Trade Association, June 15, 1892.

The Iron and Steel Industry.—F. Bleichsteiner * reviews the iron and steel industry as it exists at present. He points out that in 1870 and 1890 the production of pig iron was as follows in the countries named :—

Countries.	1870	1890.
	Tons.	Tons.
United Kingdom	5,963,515	8,000,000
United States	1,665,178	9,203,000
Germany	1,391,124	4,637,239

During the past ten years the outturn of pig iron in the United Kingdom shows but little change, while there has been a steadily increasing production in the two other countries named.

Of other countries, Hungary, Bohemia, and Moravia have shown rapidly increasing outturns during recent years. He refers to the improvements in metallurgical processes which have been introduced, and considers the question as to the supply of ore and fuel. Older processes have gradually been replaced by more modern ones, the main object being an increase in the output, combined with the gradual replacement of malleable iron by steel. The author considers the Darby recarburising process, the steel industry generally, and the comparative falling into desuetude of the puddling process. He also considers the question of the physical properties of the metals produced in relation to their chemical composition.

Consumption of Pig Iron.—Mehrtens † estimates that the annual consumption of pig iron per head of population is as follows : In Great Britain, 231 lbs. ; in Belgium and in the United States, 198 lbs. ; in Germany, 176 lbs. ; in France, 132 lbs. ; in Austria-Hungary, 66 lbs. ; in Russia, 26 lbs. ; and in British India, 2 lbs. The average for the whole world is estimated at 33 lbs.

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xl. pp. 190-192, 204-208, 216-219.

† *Zeitschrift des Vereines Deutscher Ingenieure*, vol. xxxvi., pp. 692-700.

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THE
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APPENDIX.

Form A—CANDIDATE'S RECOMMENDATION FOR ELECTION.

Form B—NOTICE OF ELECTION OF MEMBER.

Form C—OBLIGATIONS UNDERTAKEN BY ELECTED CANDIDATES.

Form D—APPLICATION FOR ARREARS OF SUBSCRIPTION.

THE IRON AND STEEL INSTITUTE.

RULES.

1. The Society shall be designated "THE IRON AND STEEL INSTITUTE."
2. The objects of the Institute shall be—

To afford a means of communication between members of the Iron and Steel Trades upon matters bearing upon their respective manufactures, excluding all questions connected with wages and trade regulations.

To arrange periodical meetings for the purpose of discussing practical and scientific subjects bearing upon the manufacture and working of iron and steel.

SECTION I.—Constitution.

3. The Institute shall consist of members who shall be more than twenty-one years of age, and shall have one or other of the following qualifications:—

- (a) Persons practically engaged in works where iron or steel is produced or worked.
- (b) Persons of scientific attainments in metallurgy, or specially connected with the application of iron and steel.

It shall be within the province of the Council to elect Honorary Members, the number not to exceed twenty.

SECTION II.—Election of Members.

4. A recommendation for admission according to Form A in the Appendix shall be forwarded to the General Secretary, and by him be laid before the Council. The recommendation shall be in writing, and be signed by not fewer than three members.

5. Such applications for admission as are approved by a majority of the Council shall be inserted on a voting list. This voting list shall specify the name, occupation, address, and proposers of the candidates, and shall be forwarded to the members at least fourteen days previous to the next general meeting, when the lists that have been returned to

the General Secretary shall be opened, only in presence of the members, by Scrutineers, to be appointed by the meeting for that purpose. The elections shall take place at the general meetings only.

[*Note.*—Gentlemen whose proposal forms are passed by the Council after the voting lists have been issued, shall be allowed to attend the subsequent general meeting; and if afterwards duly elected members, it is understood that their subscription becomes payable in respect of the year in which said meeting is held.]

6. The election shall take place by ballot, three-fifths of the votes recorded being necessary for election.

7. When the proposed candidate is elected, the General Secretary shall give him notice thereof, according to Form B, but his name shall not be added to the list of members of the Institute until he shall have paid his first annual subscription, and signed the Form C in the Appendix.

8. In the case of non-election, no mention thereof shall be made in the minutes, nor any notice given to the unsuccessful candidate.

SECTION III.—Officers and Mode of Election.

9. The officers of the Institute for the management of its affairs shall consist of one President, nine Vice-Presidents, fifteen Members of Council, a Secretary or Secretaries, and one Treasurer. All members who have filled the office of President of the Institute shall be *ex-officio* permanent members of the Council, under the title of Past-Presidents.

10. The President shall be elected for two years, and shall not be eligible for re-election until after an interval; three Vice-Presidents and five Members of the Council, in rotation, shall retire annually, but shall be eligible for re-election, unless disqualified by non-attendance during the previous year. In addition, those Vice-Presidents and Members of Council shall retire who have not attended any meeting of the Council or Institute during the previous year, unless such non-attendance has been caused by special circumstances, which shall have been duly notified to the Council.

11. Candidates shall be put in nomination at the ordinary general meeting preceding the annual meeting, when the Council shall present a list specifying which of the number are eligible for re-election. Any member shall be then entitled to add names to the list of candidates. Members may also nominate candidates for office up to one month previous to the annual meeting, the names to be sent to the General Secretary. The voting list of the proposed names shall be forwarded to the members, and must be returned to the General Secretary previous to the election.

12. Each member may erase any name or names from the lists, but the number of names on the list, after such erasure, must not exceed the number to be elected to the respective offices as before enumerated. The lists which do not accord with these directions shall be rejected by the

Scrutineers. The votes for any member who may not be elected as President or Vice-President shall count for him as Vice-President or other member of the Council. The voting to be conducted in the manner specified in Section II.

13. The Council shall have power to fill up any vacancies that may occur during their year of office.

SECTION IV.—Duties of Officers.

14. The President shall be Chairman at all meetings at which he shall be present, and in his absence one of the Vice-Presidents. In the absence of a Vice-President, the members shall elect a Chairman for that meeting.

15. The Treasurer shall hold in trust the uninvested funds of the Institute, which shall be deposited in the name of the Society at a bank approved by the Council; he shall receive all moneys, and shall pay all accounts that are properly certified as correct by the Council; and shall present, from time to time, a statement of the Society's accounts.

16. The General Secretary shall attend all meetings, shall take minutes of the proceedings, shall be responsible for the safe custody of all papers, books, and other property of the Institute, and, under the direction of the Council, shall conduct the general business of the Institute.

SECTION V.—Meetings.

17. There shall be at least two general meetings in each year, one of which shall be held in London in the Spring, and the other in August or September, in such locality as the Council may direct. The meeting in the Spring shall be the annual meeting for the election of officers.

18. Twenty members shall be entitled to call, through the General Secretary, a special meeting, the objects thereof to be stated in the requisition. The business of such meeting shall be confined to the special subjects named in the notice convening the same.

19. All members shall have notice of, and shall be entitled to attend, each meeting of the Institute, and to receive copies of the Institute's publications gratuitously.

20. No alteration of the Rules or Bye-laws shall be made except at the annual meeting, and a notice of any proposed alterations shall be given at the general meeting to be held in August or September.

SECTION VI.—Subscriptions.

21. The subscription of each member shall be two guineas per annum; and members elected after January 1st, 1870, shall pay an entrance fee of two guineas each.

22. The subscriptions shall be payable in advance on January 1st in each year. Any member whose subscriptions shall be twelve months in

arrear shall forfeit all the privileges of the Institute; and the Council, after having given due notice, in the form D in the Appendix, shall be empowered to remove such name from the lists of the Institute.

SECTION VII.—Communications of Members.

23. All communications shall be submitted to the Council, and, after their approval, shall be read at the general meetings.

24. All communications made to the Institute shall be the property of the Society, and shall be published only in the Transactions of the Institute, or by the authority of the Council.

SECTION VIII.—Property of the Institute.

25. All the property of the Institute, other than funds in the hands of the Treasurer, shall be held by three Trustees, in trust for the Society. The Trustees shall be appointed by the members in general meeting assembled; and in case any vacancy in the Trustees occurs, the same shall be filled by election at the next general meeting—the Chairman, in all cases, having a second or casting vote.

26. All books, drawings, communications, models, and the like, shall be accessible to all members according to the Bye-laws. The Council shall have power to deposit the same in such place or places as may be considered most convenient for the members.

27. Every person desirous of bequeathing to the Institute any personal property, is requested to make use of the following form in his will:—"I give and bequeath to the Trustees of the Iron and Steel Institute in London [here mention the property or sum of money intended to be bequeathed] for the use of the Institute."

SECTION IX.—Consulting Officers.

28. The members in general meeting assembled shall have power to appoint such consulting officers as may be thought desirable from time to time, and may vote them suitable remuneration.

SECTION X.—Prizes.

29. The Society may offer annually a certain sum to be appropriated in Prizes or Medals, for Essays on subjects prescribed by the Council, for inventions of a specified character, or for improvements in special departments of the iron or steel manufactures. A list of the subjects for which prizes will be given shall be presented in each Annual Report.

SECTION XI.—Dissolution.

30. The Institute shall not be broken up unless upon the vote of two-thirds of the members present at any general meeting, convened for the

purpose of considering the dissolution; and after confirmation by a similar vote, at a subsequent meeting, to be held not less than three, or more than six months after the first; and notice of this last meeting shall be duly advertised as the Council or a general meeting may advise.

APPENDIX.

FORM A.

Mr. A. B. (address in full), being of the required age, and desirous of becoming a member of the Iron and Steel Institute, we, the undersigned, from our personal knowledge, do hereby recommend him for election.

His qualifications are _____

Witness our hands this _____ day of _____ 18

_____ } *Names of
Three
Members.*

FORM B.

SIR,—I beg to inform you that on the _____ you were elected a member of the Iron and Steel Institute, but, in conformity with the Rules, your election cannot be confirmed until the accompanying form be returned with your signature, and until your entrance fee and first annual subscription (amount £ _____) be paid to me. If the first subscription is not received within two months of this date, your election will become void.

I am, Sir, your obedient Servant,

General Secretary.

_____ day of _____ 18

FORM C.

I, the undersigned, being elected a member of the Iron and Steel Institute, do hereby agree that I will be governed by the regulations of the said Institute, as they are now formed, or as they may be hereafter altered; that I will advance the interests of the Institute as far as may be in my power; provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing my name therefrom, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand this day of 18

FORM D.

SIR,—I am directed to inform you that your subscription to the Iron and Steel Institute, amounting to _____, is in arrear, and that if the same be not paid to me on or before the _____ day of _____ 18____, your name will be removed from the lists of the Institute.

I am, Sir, your obedient Servant,

_____ *General Secretary.*

LIST OF MEMBERS.

CORRECTED TO DECEMBER 31st, 1892.

HONORARY MEMBERS.

ÅKERMAN, PROFESSOR R., Bergsskolan, Stockholm.
BELGIANS, H.M. LEOPOLD II., KING OF THE, Brussels.
HEWITT, HON. ABRAM S., New York, U.S.A.
TUNNER, PETER RITTER VON, Leoben, Austria.
WALES, H.R.H. ALBERT EDWARD, PRINCE OF, K.G.
K.T., K.P., G.C.B., G.C.S.I., &c., Marlborough House, Pal
Mall, S.W.

ORDINARY MEMBERS.

*Those Marked * are Original Members.*

Elected Member	
1878	Abel, Sir Fredk. Augustus, K.C.B., F.R.S., 40 Cadogan Place, London, S.W.
1891	Adams, Geo. North, Mars Iron Works, Wolverhampton.
1891	Adams, Tom Byron, Mars Iron Works, Wolverhampton.
1890	Adamson, Joseph, Hyde, near Manchester.
1890	Adamson, Robert Lawrence, 101 Finsbury Pavement, London, E.C.
1872	Addie, James, Langloan Iron Works, Coatbridge, N.B.
1869	*Addie, John, Langloan Iron Works, Coatbridge, N.B.
1889	Adler, Harmer, Chicago, U.S.A.
1880	Addyman, Thos., West Gorton, Manchester.

Elected Member	
1888	Ainslie, Frank, <i>S. Lindal Moor Mines, Ulverston.</i>
1869	*Ainslie, W. G., <i>23 Abingdon Street, London, S. W.</i>
1872	Ainsworth, George, <i>Consett Iron Works, Consett, County Durham.</i>
1887	Aird, John, <i>37 Great George Street, London, S. W.</i>
1869	*Aitken, Henry, <i>Almond Iron Works, Falkirk, N. B.</i>
1881	Akrill, Charles, <i>Golds' Green Foundry, West Bromwich.</i>
1875	Albright, A., <i>Maricmont, Birmingham.</i>
1890	Albright, John Francis, <i>Crompton & Co., Mansion House Buildings, London, E. C.</i>
1880	Alger, Charles, <i>Hudson, New York, U. S. A.</i>
1887	Allan, George, <i>Corngreaves Works, Birmingham.</i>
1891	Allan, George, <i>10 Austin Friars, London, E. C.</i>
1883	Allan, T. A., <i>Queen Anne's Mansions, St. James' Park, London, S. W.</i>
1875	Allen, Alfred H., <i>1 Surrey Street, Sheffield.</i>
1884	Allen, Harry, <i>Endcliffe, Sheffield.</i>
1872	Allen, William Daniel, <i>Bessemer Steel Works, Sheffield.</i>
1880	Allen, W. Edgar, <i>Imperial Steel Works, Saville Street, Sheffield.</i>
1886	Alley, Stephen, <i>Sentinel Works, Glasgow.</i>
1869	*Alleyne, Sir John G. N., Bart., <i>Chevin, Belper.</i>
1875	Alleyne, Reynold Henry Newton, <i>Leeds Old Foundry, Marsh Lane, Leeds.</i>
1879	Allison, Hy. Thos., <i>Acklam Iron Coy., Middlesbrough.</i>
1874	Allport, Charles J., <i>11 Euston Square, London, N. W.</i>
1871	Allport, Howard Aston, <i>Dodworth Grove, Barnsley.</i>
1890	Alonzo, Fernando, <i>Bilbao, Spain.</i>
1889	Anderson, Alexander, <i>Tower House, Dore New Road, near Sheffield.</i>

Elected Member	
1880	Anderson, Christopher, 3 Belmont Grove, Leeds.
1875	Anderson, William, C.B., F.R.S., Lesney House, Erith, Kent.
1883	Anderson, William, Stockton-on-Tees.
1885	Andrew, Hy. Herbert, Ranmoor, Sheffield.
1873	Angus, Robert, Lugar Iron Works, Cumnock, Ayrshire.
1875	Anstice, R. E., Madeley Wood, Iron Bridge, Salop
1890	Arbel, Pierre, Rive de Gier (Loire), France.
1890	Armstrong, George, Great Western Railway, Loco. Dept., Wolverhampton.
1869	*Armstrong, Lord, C.B., Etswick Iron Works, Newcastle-on-Tyne.
1890	Armstrong, Wm. Irving, South Park, Hexham.
1892	Arriaga, Luis de, Hurtado de Amézaga, 49, Bilbao, Spain.
1885	Arrol, Thomas A., Gleniston Iron Works, Glasgow.
1890	Arrol, Sir William, Bridgeton, Glasgow.
1881	Ascherson, E., 20 Abchurch Lane, Cannon Street, London, E.
1875	Ashbury, Thomas, Ash Grove, Victoria Park, Manchester.
1887	Aspinall, Jno. A. F., Fernbank, Heaton, Bolton-le-Moors.
1881	Asthower, Frederick, Ammen, Westphalia, Germany.
1880	Atkinson, A. J., 44 London Square, Bute Street, Cardiff.
1889	Atkinson, Edward T., 24 Erlanger Road, New Cross, London, S.E.
1879	Atkinson, M. H., 21 Windsor Terrace, Newcastle-on-Tyne.
1882	Austin, Kenneth S., 5 St. Mary's Road, Harlesden, London, N.W.
1881	Baare, Fritz, Bochum, Westphalia, Germany.
1873	Bagley, Charles Jno., Moor Iron Works, Stockton-on-Tees.

Elected Member	
1877	Bagshawe, Washington, <i>Leeds.</i>
1887	Bailey, William H., <i>Salford, Manchester.</i>
1873	Bain, Sir James, <i>3 Park Terrace, Glasgow.</i>
1874	Bain, J. R., <i>Harrington Iron Works, Harrington, Cumberland.</i>
1880	Baird, Geo., <i>Fulmer, Slough.</i>
1869	*Baldwin, Alfred, <i>Wilden, near Stourport.</i>
1890	Baldwin, Stanley, <i>Wilden, near Stourport.</i>
1885	Bamforth, Thos., <i>Carron Works, Falkirk, N.B.</i>
1877	Bamlett, A. C., <i>Thirsk, Yorkshire.</i>
1880	Banister, F. Dale, <i>Stonehouse, Forest Row, Sussex.</i>
1889	Banister, Herbert, <i>London Bridge Station, London Bridge, S.E.</i>
1890	Banks, Henry, <i>5 Connaught Road, Wolverhampton.</i>
1869	*Bantock, Thomas, <i>Merridale House, Wolverhampton.</i>
1879	Barba, Joseph, <i>Creusot, France.</i>
1879	Barber, James Hy., <i>Sheffield Iron and Steel Works, Attercliffe, Sheffield.</i>
1880	Barbour, Thos., <i>Derwent Hematite Iron Works, Workington.</i>
1876	Bargate, George, <i>c/o Seaton Taylor, Esq., 5 Gray's Inn, London, W.C.</i>
1886	Barlow-Massicks, Horace, <i>Askam Iron Works, Askam-in-Furness.</i>
1869	*Barlow-Massicks, Thomas, <i>The Oaks, Millom, Cumberland.</i>
1879	Barnaby, Sir Nathaniel, K.C.B., <i>Lee, Kent.</i>
1883	Barnett, F. T., <i>15 Stanley Street, Piccadilly, Manchester.</i>
1889	Barningham, Robert B., <i>Saxenholme, Upper Chorlton Road, Manchester.</i>
1873	Barningham, Thomas, <i>Corporation Street, Manchester.</i>
1889	Barns, George T., <i>Crane Iron Company, Philadelphia, U.S.A.</i>

Elected
Member

- 1882 Barrett, W. Henry,
Willowgarth, Brentwood, Essex.
- 1880 Barrow, James,
Maesteg, Glamorganshire.
- 1885 Bartlett, Jas. H.,
American Association, Ltd., Middlesbrough, Kentucky, U.S.A.
- 1887 Barton, Albert Edward,
Eureka Furnaces, Oxmoor, Jefferson Co., Alabama, U.S.A.
- 1869 *Barton, Edward,
Carnforth Hematite Iron Works, Carnforth.
- 1881 Bayard, Paul,
16 Rue du Cherche Midi, Paris.
- 1883 Bayles, J. C.,
83 Reade Street, New York, U.S.A.
- 1873 Bayley, Jno. Clowes,
1 Queen Victoria Street, London, E.C.
- 1881 Bayliss, Moses,
St. Cuthbert's, West Heath Road, Hampstead, London, N. W.
- 1881 Bear, T. Drew,
113 Queen Victoria Street, London, E.C.
- 1890 Bearcroft, Reginald,
141 Buckingham Palace Road, London, S. W.
- 1880 Beard, A.,
5 Exchange Buildings, Swansea.
- 1886 Beard, George,
Gartcosh, Glasgow.
- 1882 Beardmore, Isaac,
Lymington Lodge, Bothwell, N.B.
- 1878 Beardmore, William,
Parkhead Rolling Mills, Glasgow.
- 1889 Beardshaw, Wm. Fredk.,
Baltic Steel Works, Sheffield.
- 1881 Beckett, Joseph S.,
Brooklyn Works, Sheffield.
- 1882 Beckwith, Jno. H.,
Knott Mill Iron Works, Manchester.
- 1889 Bedford, Joseph,
Sunny Bank, Sheffield.
- 1874 Bedson, Joseph P.,
Parkhurst, Middlesbrough.
- 1891 Bell, B. T. A.,
Ottawa, Canada.
- 1886 Bell, Charles,
21 Victoria Place, Stirling.
- 1876 Bell, Charles Lowthian,
Middlesbrough.
- 1883 Bell, H. S.,
6 Dents Road, Wandsworth Common, London, S. W.

Elected Member	
1869	*Bell, Sir Lowthian, Bart., F.R.S., <i>Rounton Grange, Northallerton.</i>
1889	Bell, Robert, <i>Clifton Hall, Ratho, Edinburgh.</i>
1869	*Bell, T. Hugh, <i>Clarence Iron Works, Middlesbrough.</i>
1886	Bell, Charles Ernest, <i>Park House, Durham.</i>
1892	Bellacosa, Narciso Ping de la, <i>8 Goya, in Madrid.</i>
1892	Bellhouse, Edward Lloyd W., <i>Fir Vale, Sheffield.</i>
1889	Bellhouse, Ernest, <i>Eagle Quay, Manchester.</i>
1888	Bennett, James, <i>12 Hamilton Drive, Glasgow.</i>
1890	Bennie, James, <i>82 Gordon Street, Glasgow.</i>
1881	Benson, R. Seymour, <i>Hope Iron Works, Stockton-on-Tees.</i>
1890	Berkley, George, <i>57 Charing Cross, London, S.W.</i>
1883	Bergendal, F. J., <i>Horndal, Sweden.</i>
1869	*Bessemer, Sir Henry, F.R.S., <i>Dennmark Hill, London, S.E.</i>
1890	Bevan, Isaiah, <i>Llanelly Chemical Works, Llanelly.</i>
1890	Billy, Edouard de, <i>Ingenieur des Mines, St. Etienne (Loire), France.</i>
1875	Birch, George, <i>3 Brentwood, Pendleton, Manchester.</i>
1890	Birkbeck, Frank, <i>Gower Iron and Tinplate Works, Penclawdd, near Swansea.</i>
1890	Birkbeck, George, <i>Gower Iron and Tinplate Works, Penclawdd, near Swansea.</i>
1890	Birkbeck, Henry, <i>34 Southampton Buildings, Chancery Lane, London, W.C.</i>
1873	Bishop, Frederick S., <i>Glawrafon, Sketty, Swansea.</i>
1887	Black, Thomas, <i>Tudhoe Iron Works, Spennymoor, County Durham.</i>
1885	Blair, George Maclellan, <i>Clutha Iron Works, Glasgow.</i>
1885	Blair, James Maclellan, <i>Clutha Iron Works, Glasgow.</i>
1875	Blair, Thomas, <i>10 Castle Hill, Sheffield.</i>

Elected Member	
1869	*Blair, Thomas S., <i>Huntingdon Furnace, Spruce Creek, P.O., Huntingdon Co. Penn., U.S.A.</i>
1878	Blake, Thomas, <i>Stockton-on-Tees.</i>
1891	Bleckly, Arthur Sanderson, <i>Bewsey Iron Works, Warrington.</i>
1881	Bleckly, C. A., <i>61 King William Street, London, E.C.</i>
1878	Bleckly, Herbert Sanderson, <i>Altrincham, Cheshire.</i>
1869	*Bleckly, John James, <i>Daresbury Lodge, Altrincham.</i>
1869	*Bleckly, W. H., <i>Thetwall Lea, near Warrington.</i>
1889	Bleichert, Adolph, <i>Leipzig, Germany.</i>
1892	Bobrŕsyk, Guillermo, <i>Calle de Gerona, Almeria, Spain.</i>
1882	Böcking, Edw., <i>Mulheim-on-Rhine, Germany.</i>
1892	Böel, Gustave, <i>16 Place Charles Rogier, Brussels.</i>
1869	*Bolkow, C. F. H., <i>Marton Hall, Middlesbrough.</i>
1880	Bollinger, Henry, <i>Milan, Italy.</i>
1884	Bond, F. W., <i>Margrave Hill, Henley-on-Thames.</i>
1888	Bond, George, <i>Brimington Hall, Chesterfield.</i>
1890	Bond, George Cresswell, <i>Aspley House, Nottingham.</i>
1892	Booth, Henry D., <i>Midvale Steel Company, Philadelphia, U.S.A.</i>
1892	Booth, John William, <i>Union Foundry and Iron Works, Rodley, near Leeds.</i>
1883	Borbeley, Ludwig, <i>Salgo Tarjan, Hungary.</i>
1891	Borner, Herman, <i>63 Billiter Buildings, Leadenhall Street, London, E.C.</i>
1887	Bott, Joseph Elton, <i>Cornwall Works, Openshaw, Manchester.</i>
1892	Bouchacourt, Henri, <i>Forges et Acieries de Denain et d'Anzin, Denain, Nord, France.</i>
1890	Bowen, Thomas, <i>Morrison, near Swansea, Glamorganshire.</i>

Elected Member	
1891	Bowing, John, <i>Fuel Works, Tilbury.</i>
1882	Bowman, Harold, <i>Knott Mill Iron Works, Manchester.</i>
1873	Bowser, Howard, <i>13 Royal Crescent, Glasgow.</i>
1889	Braby, Cyrus, <i>110 Cannon Street, London, E.C.</i>
1874	Braby, Frederick, <i>Bushey Lodge, Teddington, Middlesex.</i>
1887	Bradley, Bernard Grove, <i>Codsall House, near Wolverhampton.</i>
1888	Bradley, Wm. Henry, <i>The Oaklands, Handsworth, Birmingham.</i>
1886	Bramall, Charles, <i>Worrall, near Oughtibridge, Sheffield.</i>
1882	Bramwell, Sir F. J., Bart., <i>5 Great George Street, Westminster, London, S. W.</i>
1888	Brassey, Lord, <i>24 Park Lane, London, W.</i>
1879	Brauns, Hermann, <i>Union Works, Dortmund, Germany.</i>
1885	Breckon, J. R., <i>53 John Street, Sunderland.</i>
1887	Breda, Vincenzo Stefano, <i>Acciaierie, Terni, near Rome.</i>
1889	Bremme, Friedrich G. T., <i>Gleiwitz, Germany.</i>
1888	Bright, Alfred Charles, <i>Hawkeell Tin Plate Works, Cinderford.</i>
1890	Bright, William, <i>Fairwood Tinplate Works, Glamorganshire.</i>
1891	Broadbent, Horace, <i>Chapel Hill House, Huddersfield.</i>
1880	Brock, Aubrey, <i>110 Cannon Street, London, E.C.</i>
1872	Brockbank, William, <i>Brockhurst, Didsbury, near Manchester.</i>
1885	Brodie, Thos. Dawson, <i>5 Thistle Street, Edinburgh.</i>
1869	*Brogden, Henry, <i>Hale Lodge, Altrincham, Manchester.</i>
1869	*Brogden, James, <i>Sea Bank House, Porthcawl, near Bridgend.</i>
1885	Bromilow, John, <i>137 Warwick Road, Birmingham.</i>
1881	Brooke, Edward, <i>Edgerton, Huddersfield.</i>

Elected
Member

- 1888 Brooke, Edward Burkill,
Thorpe House, Almondbury, near Huddersfield.
- 1890 Brooke, F. H.,
Oakley House, Edgerton, Huddersfield.
- 1883 Brooks, Joseph E.,
Ters Bridge Iron Works, Stockton-on-Tees.
- 1877 Brotherhood, Peter,
Belvedere Road, Lambeth, London, S.E.
- 1874 Brown, Joseph C.,
Hazel Holm, Cleator, viâ Carnforth.
- 1872 Brown, Richard,
Haylee, Largs, N.B.
- 1873 Brown, Thomas Forster,
Cardiff.
- 1886 Browne, Frederick John,
Tay Criggan, Ealing Dean, London, W.
- 1889 Browne, John,
Portugalete, Spain.
- 1881 Brownhill, Wm.
Bentley Grange, Walsall.
- 1886 Brownhill, John Justice,
Green Lane Foundry, Walsall.
- 1883 Brown-Westhead, G.,
Gouldon House, Shelton, Stoke-on-Trent.
- 1890 Bruce, John Munro,
7 Australian Avenue, London, E.C.
- 1890 Bruce, William Duff,
17 Victoria Street, Westminster, London, S.W.
- 1884 Brundreth, Alex.,
Rhymney Iron Works, Rhymney.
- 1872 Brunlees, Sir James,
12 Victoria Street, Westminster, London, S.W.
- 1880 Brustlein, H. A.,
Acéries d'Unieux, Loire, France.
- 1876 Buchanan, A.,
Handyside & Co. (Limited), Derby.
- 1888 Buckley, James,
Bryn-y-Caeran, Llanelly.
- 1887 Buckley, Samuel,
Fern Bank, Oldham.
- 1891 Budde, Otto Karl Eduard,
21 Hochstrasse, Essen, Rhenish-Prussia.
- 1872 Bull, James,
Kingsland, Newcastle-under-Lyne.
- 1872 Bullivant, W. M.,
72 Mark Lane, London, E.C.
- 1886 Bullock, Cyrus,
67 King Street, Manchester.

Elected Member	
1888	Bullock, Joseph H., <i>Pelsall Iron Works, Walsall.</i>
1884	Bunning, Charles Z., <i>c/o Borax Coy., Ltd., 2 Macri Khan, Constantinople, Turkey.</i>
1882	Bunten, James C., <i>Anderston Foundry, Glasgow.</i>
1883	Bunting, C. V., <i>Oldwheel Steel Works, Loxley, near Sheffield</i>
1870	Burden, James A., <i>Troy, New York, U.S.A.</i>
1881	Burn, R. Scott, <i>Oak Lea, Edgeley Road, near Stockport.</i>
1873	Burns-Lindow, J. L., <i>Whitehaven.</i>
1875	Burnup, J. Morison, <i>National Conservative Club, Pall Mall, London, S.W.</i>
1883	Burnyeat, William, <i>Millgrove, Whitehaven.</i>
1886	Burridge, Stephen, Jun., <i>Parade Chambers, High Street, Sheffield.</i>
1881	Burrows, Ernest J., <i>Woodlands, Wigan, Lancashire.</i>
1891	Burrows, Thomas, <i>24 Tipton Ville, Sheffield.</i>
1880	Bush, George, <i>34 Cleveland Square, Hyde Park, London, W.</i>
1883	Bush, Dudley J. C., <i>Fort House, South Molton, North Devon.</i>
1883	Butler, B. F., <i>Kirkstall Forge, Leeds.</i>
1872	Butler, Edmund, <i>Kirkstall Forge, Leeds.</i>
1876	Butler, Isaac, <i>Panteg House, near Newport, Monmouthshire.</i>
1891	Butler, Joseph G., Jun., <i>Youngstown, Ohio, U.S.A.</i>
1889	Butler, Theobald Fitzwalter, <i>Barrow-in-Furness.</i>
1882	Butlin, William, <i>Duston Hall, near Northampton.</i>
1883	Butlin, William Henry, <i>Irthlingborough Iron Works, Wellingborough.</i>
1892	Butter, Henry Joseph, <i>Claremont, Burrage Road, Plumstead, London, S.E.</i>
1889	Byers, William Lumsdon, <i>51 West Sunnyside, Sunderland.</i>
1888	Byles, Arthur R., <i>Hopewell House, Shipley, Yorkshire.</i>

Elected Member	
1892	Caine, William Sprotson, M.P., 1 <i>The Terrace, Clapham Common, London, S.W.</i>
1877	Campbell, Daniel, <i>Harbridge, Catford Hill, London, S.E.</i>
1869	*Carbutt, Sir E. Hamer, Bart., 19 <i>Hyde Park Gardens, London, W.</i>
1879	Carnegie, A., 23 <i>Broad Street, New York, U.S.A.</i>
1883	Carr, Edward, 7 <i>Victoria Street, London, S.W.</i>
1871	Carrington, Arthur, <i>Wingerworth Iron Works, Chesterfield.</i>
1881	Carruthers, Ben., <i>Worsbro' Park, Barnsley.</i>
1880	Carson, W., <i>Wallasey, Birkenhead.</i>
1888	Carter, William Allan, 5 <i>St. Andrew Square, Edinburgh.</i>
1892	Carulla, F. J. R., 84 <i>Argyll Terrace, Derby.</i>
1872	Cassels, Jno. R., <i>Glasgow Iron Works, Glasgow.</i>
1877	Casson, Richard Smith, <i>Round Oak Iron Works, Brierley Hill.</i>
1886	Cawley, George, 358 <i>Strand, London, W.C.</i>
1891	Cayley, Claude Thornton, 54 <i>Old Broad Street, London, E.C.</i>
1889	Chadwick, David, 36 <i>Coleman Street, London, E.C.</i>
1876	Chambers, A. M., <i>Thorncliffe Iron Works, Sheffield.</i>
1872	Chapman, Henry, 69 <i>Victoria St., Westminster, S.W., and 10 Rue Lafitte, Paris.</i>
1882	Chapman, John G., <i>Tower Hill, Middleton-One-Row, Darlington.</i>
1884	Charlton, Hy., <i>Gateshead Iron Works, Gateshead.</i>
1885	Charlton, Wm., <i>Guisbrough, Yorkshire.</i>
1877	Chatwood, Samuel, <i>High Lawn, Broad Oak Park, Worsley.</i>
1872	Cheesman, Wm. T., <i>Hartlepool.</i>
1890	Chernoff, Dimitris, 25 <i>Pesotshnaya, Oulitsa, St. Petersburg, Russia.</i>

Elected
Member

- 1883 Cherrie, J. M.,
21 *Hope Street, Glasgow.*
- 1882 Church, Richard F.,
1 *Victoria Street, London, S. W.*
- 1888 Clapp, Geo. H.,
95 *Fifth Avenue, Pittsburgh, U.S.A.*
- 1886 Claughton, Gilbert H.,
Dudley.
- 1892 Claye, Edgar Havelock,
Duffield Road, Derby.
- 1892 Clayton, William Wikeley,
Railway Foundry, Hunslet, Leeds.
- 1874 Cleghorn, John,
Union Bank Chambers, Spring Gardens, London, S. W.
- 1882 Cleminson, Jas.,
Dashwood House, London, E.C.
- 1888 Clerke, Wm.,
Messrs. Grindlay & Co., Parliament Street, London, S. W.
- 1869 *Cliff, Joseph,
Frodingham Iron Works, near Doncaster, Lincolnshire.
- 1890 Cliff, Walter,
Wortley, Leeds.
- 1882 Cliff, Wm. D.,
Wortley, Leeds.
- 1875 Clive, Robert,
Clanway Colliery and Iron Works, Tunstall, Staffordshire.
- 1879 Cochrane, Alfred O.,
Coatham, Redcar.
- 1869 *Cochrane, Charles,
Green Royle, Pedmore, near Stourbridge.
- 1883 Coghlan, C.,
Hunslet Forge, Leeds.
- 1887 Coghlan, John H.,
Grosvenor House, Headingley, Leeds.
- 1891 Cole, Eugene Maurice,
118 *West 49th Street, New York, U.S.A.*
- 1883 Colley, Alfred,
44 *Wellington Road, Bilston.*
- 1890 Colley, Thos. Hairs,
North View, Scunthorpe, via Doncaster.
- 1883 Collonette, R.,
Bowling Iron Coy., Bradford, Yorks.
- 1870 Colquhoun, James,
Tredegar Iron Works, Tredegar, Monmouthshire.
- 1881 Colquhoun, James,
Stanton Iron Works, near Nottingham.
- 1891 Colquhoun, William,
St. Mary's Chambers, Cardiff.

Elected
Member

- 1877 Colver, Robert,
Continental Steel Works, Sheffield.
- 1883 Colville, D., Jun.,
Motherwell, N.B.
- 1880 Colville, John,
Motherwell, N.B.
- 1890 Commans, Robt. Edden,
52 Gracechurch Street, London, E.C.
- 1886 Cook, Joseph,
Codnor Park, Alfreton.
- 1879 Cook, Joseph, Jun.,
Washington Works, Washington, R.S.O., County Durham.
- 1890 Cook, Thomas,
Washford Road, Sheffield.
- 1874 Cooper, Arthur,
North-Eastern Steel Works, Middlesbrough.
- 1887 Cooper, Edward,
17 Burling Slip, New York, U.S.A.
- 1882 Cooper, Joseph,
West Yorkshire Iron and Coal Company, East Ardsley, Yorks.
- 1880 Cooper, Leonard,
Park Row, Leeds.
- 1873 Copeland, Charles J.,
Barrow-in-Furness.
- 1879 Copestake, Sampson,
1 Adelaide Crescent, Brighton.
- 1887 Coppée, Evence,
Engineer, Brussels.
- 1879 Cornish, Henry John,
2 White Lion Court, Cornhill, London, E.C.
- 1885 Couper, James,
Craigforth, Stirling, N.B.
- 1891 Coventry, Ernest,
7 Laurence Pountney Hill, London, E.C.
- 1876 Coventry, Joseph,
34 Linnet Lane, Sefton Park, Liverpool.
- 1878 Cowan, Alex. Bertram,
Tudhoe Iron Works, Spennymoor.
- 1883 Cowan, David,
Carron, Falkirk, N.B.
- 1891 Cowan, Capt. James Henry, R.E.,
War Office, Whitehall, London, S.W.
- 1874 Coward, Edward,
Heaton Mersey, Manchester.
- 1869 *Cowper, E. A.,
6 Great George Street, Westminster, London, S.W.

Elected Member	
1870	Cowper, Charles Edward, 6 Great George Street, Westminster, London, S.W.
1892	Craddock, George, Wire Ropeworks, Wakefield.
1886	Craggs, Henry Foxton, Rinslip Park, Middlesex.
1890	Craig, James, Deanmont, Kilmarnock, N.B.
1887	Craven, John, Osborne Street, Manchester.
1880	Craven, T. F., Craven Bros. & Co., Darnall, Sheffield.
1884	Craven, Joseph, 424 Glossop Road, Sheffield.
1883	Crawford, Andrew, Bestwood Coal and Iron Works, near Nottingham.
1892	Crawford, James, Mossbay, Workington.
1869	*Crawshay, W. T., Caversham Park, Reading.
1891	Crebbin, Alfred, The Stirling Coy., Denver, Col., U.S.A.
1886	Cremer, John Henry, 24 Superior Street, Cleveland, O., U.S.A.
1880	Croasdel, S., Spring Bank, North Side, Workington.
1869	*Crompton, George, Stanton Iron Works, Nottingham.
1877	Crompton, R. E. B., 4 Mansion House Buildings, London, E.C.
1883	Crooke, Walter, Duddon Villa, Millom, Cumberland.
1880	Crookston, A. W., 19 Wellington Street, Glasgow.
1886	Crosland, J. F. Lovelock, 67 King Street, Manchester.
1883	Crossley, W. J., Glenfield, Bowden, Cheshire.
1869	*Crossley, William, 153 Queen Street, Glasgow.
1875	Crowther, Clement, Stour Vale Iron Works, Kidderminster.
1881	Crum, John, Workington, Cumberland.
1885	Cubillo, Major Leandro, Ordnance Works, Trubia, Spain.
1885	Cumberland, John S., George Yard, Upper Thames Street, London, E.C.

Elected
Member

- 1869 *Cunninghame, John,
127 *St. Vincent Street, Glasgow.*
- 1876 Cuninghame, J. C.,
Craigends, Johnstone, N.B.
- 1884 Cuninghame, Alexander,
127 *St. Vincent Street, Glasgow.*
- 1888 Cunningham, Peter Nisbet,
Blochairn Steel Works, Glasgow.
-
- 1882 Daelen, R. M.,
Kurfürstenstrasse, Düsseldorf, Germany.
- 1869 *Dale, David,
West Lodge, Darlington.
- 1881 Dalgliesh, Richard,
The Limes, Asfordley, Melton Mowbray.
- 1886 Dalton, George,
The Yews, Headingley, Leeds.
- 1887 Daniel, Edward Rice,
Cwmgelly, Swansea.
- 1889 Danielsson, Carl L.,
Bofors Steel Works, Bruksdisponent, Sweden.
- 1882 Danks, Samuel J.,
Hadley Park, near Wellington, Salop.
- 1891 Darby, Alfred,
Wrexham.
- 1880 Darby, J. H.,
Brymbo Iron Works, near Wrexham.
- 1891 Darley, Edward Charles,
Middlesbrough, Kentucky, U.S.A.
- 1889 Davenport, Russell W.,
South Bethlehem, Pa., U.S.A.
- 1870 Davey, George H.,
Baglan, near Neath, Glamorganshire.
- 1880 Davey, Henry,
3 *Princes Street, Westminster, London, S.W.*
- 1884 Davie, Thomas,
Waverley Iron and Steel Works, Coatbridge, N.B.
- 1874 Davies, Geo. William,
Hawbush Cottage, Stourbridge.
- 1889 Davies, Jasper Gustavus Silvester,
Messrs. Bolckow, Vaughan & Co., Middlesbrough.
- 1882 Davies, John B.,
Bilbao, Spain.

Elected Members	
1889	Davies, William. <i>Atlas Works, Sheffield.</i>
1882	Davies, William H., <i>Glansychan, Abersychan, near Pontypool, Monmouthshire.</i>
1875	Davis, Alfred, <i>2 St. Ermin's Mansions, Westminster, London, S.W.</i>
1878	Davis, E. Prosser, <i>Awsworth Iron Works, Ilkeston, near Nottingham.</i>
1891	Davis, James, <i>Berkley Terrace, Newburn, Newcastle-on-Tyne.</i>
1890	Davis, William, <i>4 Gloucester Place, Swansea.</i>
1883	Davy, Abraham, <i>The Oaks, Pitsmoor, Sheffield.</i>
1889	Davy, Charles, <i>Park Iron Works, Sheffield.</i>
1883	Davy, David, <i>Broom Croft, Parkhead, Sheffield.</i>
1883	Dawson, Bernard, <i>York House, Malvern Link, Worcester.</i>
1890	Day, Richard, <i>Hall Croft, Horbury, near Wakefield.</i>
1887	Deacon, George Frederick, <i>Victoria Mansions, 32 Victoria Street, London, S.W.</i>
1887	Dean, William, <i>Great Western Railway, Swindon.</i>
1874	Deby, Julien, <i>31 Belsize Avenue, Hampstead, London, N.W.</i>
1891	Deegun, Thomas, <i>Lewis Block, Pittsburgh, Pa., U.S.A.</i>
1886	Dees, James Gibson, <i>Floraville, Whitehaven.</i>
1885	*Deighton, Wm., <i>13 Hyde Terrace, Leeds.</i>
1892	Delano, Frederic A., <i>Burlington and Quincy Railway, Chicago, Ill., U.S.A.</i>
1879	Delorme, I., <i>Société de Montain à Outreau, Pas-de-Calais, France.</i>
1881	Denne, Thos. M., <i>Dufferin Street, London, S.E.</i>
1892	Dennis, Arthur, <i>11 Billiter Street, London, E.C.</i>
1880	Dering, G. E., <i>Lockleys, Welwyn, Herts.</i>
1889	Devereux, Walter B., <i>Glenwood Springs, Colorado, U.S.A.</i>
1888	Devonshire, The Duke of, <i>Devonshire House, London, W.</i>

Elected Member	
1879	Dick, G. Alex., <i>110 Cannon Street, London, E.C.</i>
1884	Dick, Frank Wesley, <i>Palmer's Shipbuilding and Iron Coy., Jarrow.</i>
1876	Dickinson, Samuel, <i>Woodfield, Wolverhampton.</i>
1889	Dickinson, Edward, <i>Meersbrook Bank, Sheffield.</i>
1884	Dickinson, John, <i>Park House, Sunderland.</i>
1888	Dickinson, Richard Elihu, <i>Bowling Iron Coy., Bradford, Yorkshire.</i>
1889	Dickson, John, <i>Glaidsdale Iron Works, Grosmont, Yorkshire.</i>
1880	Dixon, D. W., <i>Brotton Mines, Saltburn-by-the-Sea.</i>
1869	*Dixon, Sir Raylton, <i>Cleveland Shipyard, Middlesbrough.</i>
1890	Dixon, Samuel, <i>Victoria Iron Works, Dickinson Street, Salford.</i>
1890	Dobson, James Murrey, <i>33 Great George Street, London, S.W.</i>
1884	Dodd, Benj., <i>Bearpark Colliery, County Durham.</i>
1872	Dodds, Matthew B., <i>Stockton-on-Tees.</i>
1886	Donald, Wm. J. Alex., <i>27 St. Vincent Place, Glasgow.</i>
1890	Dore, Samuel Lammis, <i>Corbet Court, Gracechurch Street, London, E.C.</i>
1874	Dorman, A. J., <i>Middlesbrough.</i>
1870	Douglas, C. P., <i>Parliament Street, Consett, Durham.</i>
1875	Dove, George, Jun., <i>Hatfield House, Hatfield, near Doncaster.</i>
1869	*Downey, Alfred C., <i>Coatham Iron Works, Middlesbrough.</i>
1877	Downie, Alexander, <i>The Ashes, Stanhope, Weardale.</i>
1881	Downing, Samuel, <i>Morlands, Sutton Road, Erdington, Birmingham.</i>
1889	Dreux, A., <i>Acieries de Longwy, Mont St. Martin, France.</i>
1888	Dronsfield, William, <i>Alexandra Park, Oldham.</i>
1886	Drown, Thomas M., <i>Institute of Technology, Boston, U.S.A.</i>

Elected
Member

- 1890 Drummond, S. R.,
Lumb Lane Mills, Bradford, Yorkshire.
- 1886 Dudley, Charles B.,
Altoona, Pennsylvania, U.S.A.
- 1891 Duffield, James,
Ashfield House, Workington.
- 1889 Duncan, David John Russell,
Kilmux, Leven, Fifeshire.
- 1891 Duncan, Hon. George A. P. H.,
9 Gloucester Street, Boston, Mass., U.S.A.
- 1888 Dunkerley, C. Chorlton,
Hurst Dale, Bowden, Cheshire.
- 1888 Dunlop, Alexander M.,
3 Old Palace Yard, Westminster Abbey, London, S.W.
- 1890 Dunnachie, Archibald Hendry,
Glenboig, Coatbridge, N.B.
- 1875 Dunnachie, James,
Glenboig, Coatbridge, N.B.
- 1875 Durfee, Wm. F.,
77 Jewitt Avenue, West New Brighton, New York, U.S.A.
- 1881 Durham, The Earl of,
Lambton Castle, Fence Houses, Co. Durham.
- 1884 Durieux, Aimé,
18 Avenue Matignon, Paris.
- 1884 Dyer, H. S.,
Condercum House, Newcastle-on-Tyne.
-
- 1885 Eadon, Robt. Renton,
President Works, Sheffield.
- 1882 Eagland, W. H.,
74 Wellington Street, Leeds.
- 1886 Earle, Wm. Norecliffe,
Cwm Avon, Port Talbot, S. Wales.
- 1882 Easton, Edward,
Delahay Street, Westminster, London, S.W.
- 1887 Eccles, Herbert,
Briton Ferry Steel Coy., Ltd., Glamorganshire.
- 1880 Edge, John H.,
Coalport Works, Shifnal, Salop.
- 1884 Edmonds, R.,
Royal Arsenal, Woolwich.
- 1889 Edwards, Daniel,
Morrison, R.S.O., Glamorganshire.
- 1889 Edwards, Wm. Henry,
Morrison, R.S.O., Glamorganshire.

Elected
Member

- 1887 Egleston, Thomas,
School of Mines, Columbia College, New York, U.S.A.
- 1880 Ehrhardt, B.,
Cainsdorf, Saxony.
- 1883 Ellacott, Robert H.,
Engineering Works, Plymouth.
- 1877 Elliot, Sir George, Bart., M.P.,
23 Great George Street, London, S.W.
- 1885 Ellis, Arthur D.,
Bowling Iron Company, Bradford, Yorks.
- 1889 Ellis, Arthur Stanley,
Stafford Street, Wednesbury.
- 1883 Ellis, E. William,
Church Place, New Swindon, Wilts.
- 1875 Ellis, John D.,
Atlas Works, Sheffield.
- 1890 Ellis, Joseph,
Workington Hematite Iron and Steel Works, Workington.
- 1884 Ellis, Thomas Leonard,
North British Iron Works, Coatbridge, N.B.
- 1879 Ellison, John,
Rose Hill, Harrington, Cumberland.
- 1892 Elsner, Jules,
80 Lombard Street, London, E.C.
- 1891 Emory, Wm. Hemsley,
11 St. George's Place, London, S.W.
- 1874 Euchene, Albert,
8 Boulevard de Versailles, St. Cloud (Seine et Oise), France
- 1882 Evans, Christmas,
Heolgerrig, Merthyr Tydfil.
- 1873 Evans, David,
Bolckow, Vaughan, & Co., Middlesbrough.
- 1890 Evans, David,
Llangennech Park, Llanelly.
- 1889 Evans, Evan D.,
*c/o H. Borner & Co., 63 Billiter Buildings, Leadenha
Street, London, E.C.*
- 1881 Evans, J. Campbell,
The Ferns, King's Road, Clapham Park, London, S.W.
- 1878 Evans, Richard,
Consett Iron Works, Consett, Durham.
- 1884 Evans, R. K.,
*c/o Commans & Co., Adelaide Chambers, 52 Gracechurch
Street, London, E.C.*
- 1869 *Evans, William,
Nant Cottage, Ilkley, Yorkshire.
- 1882 Evans, William,
Cyfarthfa, Merthyr Tydfil, Glamorganshire.

Elected Member	
1883	Evans, William, <i>The Cliff, Ferryside, Carmarthenshire.</i>
1891	Evans, William, <i>Oak House, Blaenavon, Mon.</i>
1889	Evrard, Alfred, <i>19 Boulevard des Italiens, Paris.</i>
1890	Faber, Edward Grey, <i>3 Harold Road, Upper Norwood, London, S.E.</i>
1892	Fackenthal, B. F., Jun., <i>Durham Iron Works, Riegelsville, Pa., U.S.A.</i>
1869	*Farley, Reuben, <i>Summit Foundry, West Bromwich.</i>
1869	*Farnworth, William, <i>Swindon Iron Works, Dudley.</i>
1877	Faustman, E., <i>c/o E. Ristori, 9 Victoria Street, London, S.W.</i>
1872	Faviell, F. H., <i>45 and 46 Leadenhall Street, London, E.C.</i>
1886	Fearnehough, Walter, <i>Garden Street, Sheffield.</i>
1890	Feldtmann, Gottlieb Heinrich, <i>St. Bees, Cumberland.</i>
1886	Feldtmann, Rudolph, <i>24 St. Vincent Place, Glasgow.</i>
1889	Fellows, Samuel James, <i>Compton, Wolverhampton.</i>
1890	Fincken, C. W., <i>Hoyland Colliery, near Barnsley.</i>
1885	Finlayson, Finlay, <i>Vulcan Foundry, Coatbridge, N.B.</i>
1889	Firbank, Joseph Tom, <i>Railway Approach, London Bridge, S.E.</i>
1888	Firth, Ambrose, <i>Newhall Iron Works, Sheffield.</i>
1882	Firth, Lewis J., <i>Norfolk Works, Sheffield.</i>
1889	Firth, Wm. Edgar, <i>Midvale Steel Coy., Nicetown, Philadelphia, U.S.A.</i>
1881	Fischer, M. F., <i>Hallesche Strasse, 9, Magdeburg, Germany.</i>
1883	Fisher, Edward, <i>West Walk, Leicester.</i>
1870	Fisher, E. K., <i>Hill Crest, Market Harborough.</i>

Elected Member	
1883	Fitzsimons, Edward, 3 <i>St. James Terrace, Barrow-in-Furness.</i>
1887	Flagler, John H., 104 <i>John Street, New York, U.S.A.</i>
1881	Flather, William T., <i>Love Street Steel Works, Sheffield.</i>
1877	Fletcher, William, <i>Brigham Hill, viâ Carlisle.</i>
1885	Fletcher, Wm., <i>Eagle Foundry, Booth Street, Salford.</i>
1891	Flett, George, 101 <i>Leadenhall Street, London, E.C.</i>
1880	Forbes-Leith, A. J., 46 <i>Wall Street, New York, U.S.A.</i>
1892	Ford, Edward Livingston, <i>Youngstown, Ohio, U.S.A.</i>
1872	Forester, W. H., <i>Sketty Park, Swansea.</i>
1883	Forster, G. Baker, <i>Farnley Hill, Corbridge.</i>
1879	Forsyth, Robert, 1035 <i>Rookery, Chicago, U.S.A.</i>
1874	Fossick, William G., 86 <i>Cannon Street, London, E.C.</i>
1880	Foster, H. Le Neve, <i>Earl of Dudley's Round Oak Iron and Steel Works, Brierley Hill.</i>
1869	*Foster, W. O., <i>Stourbridge Iron Works, Stourbridge.</i>
1879	Fould, Alphonse, <i>Pompey, Meurthe-et-Moselle, France.</i>
1892	Fowler, William Henry, 6 <i>Victoria Approach, Manchester.</i>
1884	Fownes, Hy., <i>Tyne Forge Company, Ouseburn, Newcastle-on-Tyne.</i>
1877	Fox, Samson, <i>Leeds Forge Company, Armley, Leeds.</i>
1892	Frank, Julius, <i>Nievernerhütte, near Ems, Germany.</i>
1886	Franki, James Peter, <i>Morts Dock and Engineering Co., Sydney, N.S.W.</i>
1888	Fraser, Graham, <i>Nova Scotia Steel Works, New Glasgow, Nova Scotia.</i>
1889	Freeston, Thomas Edgar, <i>Attercliffe, Sheffield.</i>
1882	Freir, William E., 42 <i>Cannon Street, London, E.C.</i>

Elected Member	
1873	French, William, 59 <i>St. Vincent Street, Glasgow.</i>
1886	Frew, John, <i>Carron Iron Works, Carron, N.B.</i>
1881	Frey, C. A. von, <i>I. Maximilianstrasse 2, Vienna, Austria.</i>
1882	Fromm, E., <i>Maximilianhütte, Regensburg, Bavaria.</i>
1879	Fry, John E., <i>Springfield Iron Works, Illinois, U.S.A.</i>
1869	Fry, Theodore, M.P., <i>Darlington.</i>
1884	Galbraith, Wm., <i>Wingerworth Iron Works, Chesterfield.</i>
1882	Galloway, Arthur Walton, <i>Knott Mill Iron Works, Manchester.</i>
1870	Galloway, Charles John, <i>Knott Mill Iron Works, Manchester.</i>
1885	Galloway, Edward N., <i>Knott Mill Iron Works, Manchester.</i>
1875	Galloway, John, Jun., J.P., <i>The Cottage, Old Trafford, Manchester.</i>
1882	Galton, Sir Douglas, C.B., D.C.L., F.R.S., <i>12 Chester Street, Grosvenor Place, London, S.W.</i>
1888	Gamble, Joseph, <i>Sheffield.</i>
1891	Garnier, Jules, <i>14 Rue de Berlin, Paris.</i>
1884	Garrett, Geo., <i>Waverley Iron and Steel Works, Coatbridge, N.B.</i>
1889	Garrison, F. Lynwood, <i>South-East Corner, 4th Chestnut Street, Philadelphia, U.S.A.</i>
1875	Gautier, Ferdinand, <i>156 Boulevard Malesherbes, Paris.</i>
1888	Gayley, James, <i>Edgar-Thomson Steel Works, Pittsburgh, U.S.A.</i>
1884	Geen, Geo., <i>Ivor Villa, Gold Tops, Newport, Monmouthshire.</i>
1890	Geen, Wm. Rowe, <i>Claremont, Newport, Monmouthshire.</i>
1890	Geny, Maurice, <i>31 Rue de Rome, Paris.</i>
1890	Gielgud, Henry, <i>31 Queen Victoria Street, London, E.C.</i>

- Elected Member
- 1875 Gilchrist, P. C., F.R.S.,
101 *Palace Chambers, 9 Bridge Street, London, S.W.*
- 1869 *Gilkes, Gilbert,
Lynnside, Kendal.
- 1881 Gill, William,
Orconera Iron Company, Bilbao, Spain.
- 1872 Gillott, Thomas,
Butterley Iron Works, Alfretton, Derbyshire.
- 1890 Gilmour, James Anderson,
Portland Colliery, Kilmarnock, N.B.
- 1869 *Gjers, John,
Ayresome Iron Works, Middlesbrough.
- 1882 Gjers, Lawrence F.,
3 *Southfield Villas, Middlesbrough.*
- 1886 Gledhill, John M.,
Sir Joseph Whitworth & Co., Manchester.
- 1890 Glenn, Joseph Barber,
7 *Poultry, London, E.C.*
- 1885 Glover, Ben Bradshaw,
Lyme Grove, St. Helens, Lancashire.
- 1871 Goldwyer, John E.,
Witford House, Briton Ferry, Glamorganshire.
- 1885 Goodchap, Charles A.,
109 *Jermyn Street, London, S.W.*
- 1886 Goransson, A. H.,
Sandviken Steel Works, Sweden.
- 1887 Gordon, Alex.,
Hamilton, Ohio, U.S.A.
- 1885 Gordon, Fred. W.,
226 *Walnut Street, Philadelphia, Pa., U.S.A.*
- 1873 Gordon, Joseph G.,
Queen Anne's Mansions, London, S.W.
- 1880 Gössell, O., Jun.,
110 *Cannon Street, London, E.C.*
- 1878 Gottschalk, Alexandre,
13 *Rue Auber, Paris.*
- 1887 Goulty, Wallis Rivers,
Albert Chambers, Albert Square, Manchester.
- 1889 Graham, Alexander Macdougall,
20 *Dixon Street, Glasgow.*
- 1886 Grant, T. Maxwell,
Winlass Engine Works, 100 Hydepark Street, Glasgow.
- 1891 Gray, Matthew,
Steel Works, West Hartlepool.
- 1892 Greathead, John Henry,
15 *Victoria Street, London, S.W.*
- 1888 Green, Sir Edward, Bart.,
Wakefield.

Elected Member	
1886	Green, Edward Llewellyn, <i>Fairy Land, Neath, South Wales.</i>
1881	Green, John, <i>Tin Plate Works, Abercarn, Monmouthshire.</i>
1885	Greenwood, William Henry, <i>Birmingham Small Arms and Metal Company, Adderley Park Works, Birmingham.</i>
1889	Gregory, Joseph, <i>Whalley Cottage, Upper Chorlton Road, Manchester.</i>
1876	Greiner, A., <i>Société John Cockerell, Seraing, Belgium.</i>
1887	Griffin, S., <i>Cleveland House, Bath.</i>
1891	Griffin, Thomas Augustus, <i>Phoenix Buildings, Chicago, U.S.A.</i>
1884	Griffith, W., <i>Sheffield.</i>
1886	Griffiths, Azariah, <i>The Hollies, Falkirk, N.B.</i>
1892	Griffiths, Ernest, <i>Griffithstown, near Newport, Mon.</i>
1891	Griffiths, John Rowland, <i>Tintern, near Chepstow.</i>
1874	Griffiths, N. R., <i>Wrexham.</i>
1890	Grigg, Richard, <i>The Salt Union, Middlesbrough.</i>
1879	Gruson, H., <i>Magdeburg-Buckau, Germany.</i>
1875	Guest, Josiah, <i>Victoria and Albert Iron Foundries, West Bromwich.</i>
1889	Gubbins, R. R., <i>North Kent Iron Coy., Erith, Kent.</i>
1888	Guillaume, Theodor, <i>Mulheim-on-the-Rhine, Germany.</i>
1882	Guillaume, Emil, <i>Mulheim-on-the-Rhine, Germany.</i>
1890	Guillaume, Max, <i>Mulheim-on-the-Rhine, Germany.</i>
1875	Gunter, William, <i>Central Engineering Works, Oldham.</i>
1883	Gutmann, Max Ritter von, <i>I Kantgasse, 6, Vienna, Austria.</i>
1890	Guy, Henry Augustus, <i>Invincible Steel Works, Sheffield.</i>

Elected Member	
1878	Haarmann, August, <i>Osnabrück Iron and Steel Works, Osnabrück, Prussia.</i>
1887	Hackney, Samuel John, <i>The Titanic Steel Coy., Manchester.</i>
1885	Hadfield, Robt. Abbott, <i>Fairfield, Sheffield.</i>
1891	Haedenkamp, Hermann, <i>8 Maestrasse, Essen, Rhenish Prussia.</i>
1884	Haggie, D. H., <i>Sunderland.</i>
1889	Haggie, Peter Sinclair, <i>Gateshead-on-Tyne.</i>
1878	Hall, J. F., <i>Norbury, Pitsmoor, Sheffield.</i>
1891	Hall, John William, <i>Ivy House, Bilston.</i>
1888	Hallbauer, Joseph, <i>Lauchhammer Iron Works, Lauchhammer, Germany.</i>
1879	Hallopeau, Alfred, <i>24 Rue de Lyon, Paris.</i>
1873	Halpin, Druitt, <i>9 Victoria Chambers, London, S.W.</i>
1891	Hamilton, Alex. Thornton, <i>Etna Furnace Coy., Georgia, U.S.A.</i>
1885	Hamilton, James, <i>Coltress Iron Works, Newmains, N.B.</i>
1881	Hammond, Robert, <i>117 Bishopsgate Street Within, London, E.C.</i>
1870	Hampton, Thomas, <i>Maryport Iron Works, Maryport.</i>
1888	Haniel, Hugo, <i>Haniel & Lueg, Dusseldorf, Germany.</i>
1880	Hannay, G. Kerr, <i>Hill Fort Ulverston.</i>
1884	Hansell, James Burne, <i>Moor Oaks Road, Broomhill, Sheffield.</i>
1886	Hansell, Richard Alexander, <i>Sheffield.</i>
1875	Hansell, R. B., <i>3 Maule Terrace, Partick, Glasgow.</i>
1869	*Hanson, William, <i>Newport Iron Works, Middlesbrough.</i>
1884	Harbord, F. W., <i>Pennfields, Wolverhampton.</i>
1869	*Hardeman, Charles H., <i>The Brampton, Newcastle-under-Lyne.</i>
1875	Harding, George, <i>Biddulph Iron Works, Stoke-on-Trent.</i>

Elected Member	
1875	Harding, Joshua, <i>Norton Iron Works, near Burslem, Staffordshire.</i>
1883	Hardisty, John, <i>75 Grange Road West, Middlesbrough.</i>
1890	Harley, Walter, <i>Smethwick.</i>
1890	Harrah, Chas. J., <i>Midvale Steel Coy., Philadelphia, U.S.A.</i>
1889	Harris, Anthony, <i>Grove Hill, Middlesbrough.</i>
1888	Harrison, George Herbert, <i>Hagley, near Stourbridge.</i>
1876	Harrison, G. K., <i>Hagley, near Stourbridge.</i>
1882	Harrison, Wm. B., <i>Cyclops Iron Works, Walsall.</i>
1877	Hart, John, <i>New Exchange Buildings, Middlesbrough.</i>
1876	Hartley, Jno., <i>Heely, Sheffield.</i>
1884	Hartman, John M., <i>1235 North Front Street, Philadelphia, U.S.A.</i>
1881	Hartmann, Jean, <i>Rue des Trois Rois, Mulhouse, Alsace, Germany.</i>
1891	Hartshorne, Joseph, <i>Pottstown, Pa., U.S.A.</i>
1888	Harvey, Alfred, <i>Steel and Iron Works Manager, Cwm Avon, Port Talbot, Glamorganshire.</i>
1888	Harvey, Charles, <i>3 Victoria Street, Westminster, S.W.</i>
1876	Harvey, Wm., <i>Thornlee Park Villa, Wishaw, near Glasgow.</i>
1882	Haswell, Chas. J. F., <i>Theresianungasse, 10, Vienna, Austria.</i>
1879	Hatton, William, <i>Hill Grove, Kidderminster.</i>
1875	Hatton, Geo., <i>The Lawn, Hagley, Stourbridge.</i>
1876	Hawdon, William, <i>Newport Iron Works, Middlesbrough.</i>
1882	Hawksley, Chas., <i>30 Great George Street, Westminster, London, S.W.</i>
1883	Hawksley, G. W., <i>Brightside Engine Works, Sheffield.</i>
1882	Hawksley, Thos., F.R.S., <i>30 Great George Street, Westminster, London, S.W.</i>

Elected
Member

- 1886 Hay, Alex. Marshall,
35 *New Broad Street, London, E.C.*
- 1882 Hay, Alexander S.,
Nettlestone, South Hampstead, London, N.W.
- 1887 Hayes, Edmund,
Union Bridge Company, Buffalo, U.S.A.
- 1890 Head, Archibald P.,
Queen's Square, Middlesbrough.
- 1869 *Head, Charles A.,
Teesdale Iron Works, Stockton-on-Tees.
- 1882 Head, H. E.,
24 *Auriol Road, West Kensington, London, W.*
- 1869 *Head, Jeremiah,
Queen's Square, Middlesbrough.
- 1884 Head, John, F.G.S.,
12 *Queen Anne's Gate, Westminster, London, S.W.*
- 1881 Heath, A. H.,
Madeley Manor, Newcastle, Staffordshire.
- 1873 Heath, James,
Clayton Hall, Newcastle, Staffordshire.
- 1869 *Heath, Robert,
Biddulph Iron Works, Stoke-on-Trent.
- 1872 Heath, Robert, Jun.,
Biddulph Iron Works, Stoke-on-Trent.
- 1875 Heathfield, R.,
Foxlydiate, near Redditch.
- 1880 Hedley, Robt.,
Tudhoe Iron Works, Spennymoor.
- 1873 Hedley, Thomas,
2 *Fenham Terrace, Newcastle-on-Tyne.*
- 1884 Helder, Aug.,
Corkickle, Whitehaven, Cumberland.
- 1878 Helmholtz, Otto,
Rheinische Stahlwerke, bei Ruhrort, Prussia.
- 1892 Henderson, James,
Frodingham, near Doncaster.
- 1889 Henderson, Norman M'Farlane,
Broxburn Lodge, Broxburn.
- 1890 Hennin, Alphonse,
Springfield Iron Coy., Springfield, Illinois, U.S.A.
- 1889 Henning, Gustavus C.,
726 *Temple Court, 5 Beckman Street, New York, U.S.A.*
- 1884 Heslop, Christopher,
Upleatham Mines, Upleatham, R.S.O., Yorkshire.
- 1892 Heussey, Comte du Pontavice de,
French Embassy, Albert Gate, London, S.W.
- 1869 *Hewlett, Alfred,
Kirkless Hall Iron Works, Wigan.

Elected Member	
1873	Hewlett, W. H., <i>Wigan Coal and Iron Company, Wigan.</i>
1879	Heywood, Henry, <i>Cardiff.</i>
1892	Hibbard, Henry Denning, <i>Taylor Iron and Steel Co., High Bridge, New Jersey, U.S.A.</i>
1879	Hick, John, M.P., <i>Mytton Hall, Whalley, Blackburn.</i>
1879	Hickman, Sir Alfred, <i>22 Palace Gardens, Kensington, London, W.</i>
1883	Hickman, A. W., <i>Spring Vale Furnaces, Wolverhampton.</i>
1881	Higginbottom, James, <i>Seel Street, Liverpool.</i>
1879	Higson, Jacob, <i>68 New Bridge Lane, Stockport.</i>
1890	Hill, Alfred, <i>Newport Wire Mills, Middlesbrough.</i>
1878	Hill, Francis, <i>Stocksbridge, near Sheffield.</i>
1885	Hill, John, <i>Norton, near Stockton-on-Tees.</i>
1886	Hill, Joseph, <i>White House, Ashley, near Market-Drayton.</i>
1885	Hills, Arnold F., <i>Thames Iron Works, London, E.</i>
1874	Hilton, Franklin, <i>Ebbw Vale Co., Limd., Ebbw Vale, Mon.</i>
1885	Hinchliffe, John, <i>Bullhouse Colliery, Penistone.</i>
1883	Hingley, Benjamin, M.P., <i>Netherton Iron Works, Dudley.</i>
1889	Hingley, George Benjamin, <i>Netherton Iron Works, Dudley.</i>
1890	Hipkins, William, <i>Summerfield, 36 Wheeley's Road, Edgbaston.</i>
1886	Hirst, Daniel Jones, <i>Blaenavon Works, Blaenavon, Mon.</i>
1874	Hobson, Henry, <i>The Hollies, Norton, Stockton-on-Tees.</i>
1879	Hobson, J. F., <i>Washington, County Durham.</i>
1884	Hodges, Petronius, <i>142 Burngreave Road, Sheffield.</i>
1878	Hodgson, John, <i>North Terrace, Darlington.</i>
1873	Hodgson, John Lee, <i>Hooley Range, Heaton-Moor, Stockport.</i>

Elected
Member

- 1886 Hodson, James,
Stoke-on-Trent.
- 1891 Hoffstat, F. N.,
208 Wood Street, Pittsburgh, Pa., U.S.A.
- 1887 Holgate, Thos. Edward,
146 Blackburn Road, Darwen.
- 1874 Holland, C. B.,
Ebbw Vale Works, Newport, Mon.
- 1891 Holland, Col. Trevenen James, C.B.,
Mount Ephraim House, Tunbridge Wells.
- 1890 Holliday, Henry,
Leeds Steel Works, Leeds.
- 1891 Hollingworth, Edward,
Woods House, Dobcross, near Oldham.
- 1889 Hollingworth, James,
Dobcross, Oldham.
- 1873 Hollingsworth, A. T.,
36 Bedford Street, Strand, London, W.C.
- 1880 Hollis, H. W.,
Thornville House, Darlington.
- 1876 Holt, Henry Percy,
The Cedars, Didsbury, Manchester.
- 1890 Holtzer, Louis,
Unieux, Loire, France.
- 1871 Homer, Charles J.,
Ivy House, Stoke-upon-Trent.
- 1873 Hopkinson, John,
Inglewood, St. Margaret's Road, Bowden, Cheshire.
- 1879 Horsfall, G. H., Jun.,
Larkfield, Toxteth Park, Liverpool.
- 1888 Horsfield, Arthur,
High Bank, Horbury, near Wakefield.
- 1891 Horsfield, J. H. H.,
5 St. Andrew Square, Edinburgh.
- 1889 Horsfield, Samuel,
Palmer's Steel Depot, Jarrow-on-Tyne.
- 1888 Horton, Enoch,
The Grange, Bescot, near Walsall.
- 1883 Horton, S. B. L.,
Cartrev, Prior's Lee, Shifnal.
- 1869 *Horton, Thomas E.,
Penmaenmaur, North Wales.
- 1885 Hosking, Richard,
Clarence House, Dalton-in-Furness.
- 1873 Houghton, John,
Broom Cottage, Appleton (Cheshire), near Warrington.
- 1880 Houldsworth, Jas.,
36 Queen's Gate, South Kensington, London, W.

Elected Member	
1882	Houldsworth, W. J., 36 <i>Queen's Gate, South Kensington, London, W.</i>
1891	Howat, William, <i>Cranstonhill, Glasgow.</i>
1869	*Howson, R., <i>Exchange Place, Middlesbrough.</i>
1884	Hoyle, James Rossiter, <i>Norfolk Works, Sheffield.</i>
1880	Huart, Baron F. d', <i>Longwy, Moselle, France.</i>
1885	Hudson, Wm. John, <i>Woodside Iron Works, Dudley.</i>
1880	Hudspith, W., <i>Haltwhistle, Northumberland.</i>
1882	Huggett, J. A., <i>West Rocks, Grand Parade, Eastbourne.</i>
1877	Hughes, Arthur D., c/o <i>F. Taylor, 90 Cannon Street, London, E.C.</i>
1888	Hughes, John James, c/o <i>F. Taylor, 90 Cannon Street, London, E.C.</i>
1887	Hulse, J. Whitworth, <i>Ordsal Works, Salford, Manchester.</i>
1882	Hulse, Wm. W., <i>Ordsal Works, Salford, Manchester.</i>
1872	Humphreys, A. W., 45 <i>William Street, New York, U.S.A.</i>
1890	Hunsiker, Millard, <i>Carnegie, Phipps & Co., Pittsburgh, Pa., U.S.A.</i>
1888	Hunt, Alfred E., 95 <i>Fifth Avenue, Pittsburgh, U.S.A.</i>
1889	Hunt, Charles, <i>Windsor Street, Birmingham.</i>
1890	Hunter, Wm., <i>Petershill Road, Glasgow.</i>
1881	Huntington, Alfred Kirby <i>King's College, London, W.C.</i>
1882	Hutchinson, Thomas C., <i>Hilda House, Middlesbrough.</i>
1889	Hutchinson, William, <i>Staffordshire Steel Company, Bilston.</i>
1883	Hutton, A. W., <i>Cyclops Iron Works, Walsall.</i>
1876	Hutton, Robert, <i>Batts Foundry, Whitby.</i>

Elected
Member

- 1875 Ianson, James,
Fairfield House, Darlington.
- 1869 *Ianson, J. C.,
6 Britannia Terrace, Saltburn by the Sea.
- 1876 Ingham, William P.,
Middlesbrough.
- 1883 Ingram, C. W.,
Falconhyrst, Penarth, Cardiff.
- 1890 Jack, Alex. G. M.,
Meadowhead, Grimesthorpe Road, Sheffield.
- 1890 Jackman, Joseph,
Persberg Steel Works, Sheffield.
- 1884 Jacks, William,
7 Royal Bank Place, Glasgow.
- 1881 Jackson, John,
Stubben Edge, Chesterfield.
- 1873 Jackson, W. F.,
Herndale House, Litton, viâ Stockport.
- 1881 Jacobi, Hugo,
Gutehoffnungshütte, Westphalia, Germany.
- 1869 *Jaffrey, G. W.,
Westland Terrace, 17 Robertson Street, Greenock.
- 1885 Jambille, Louis,
Maubeuge, France.
- 1889 James, Charles Henry,
8 Courtland Terrace, Merthyr Tydfil.
- 1889 James, Enoch,
Dowlais Cardiff Works, Cardiff, Monmouthshire.
- 1873 James, Phineas,
Abercarn Estate Office, Abercarn, Newport, Mon.
- 1884 James, John W. Hy.,
32 Victoria Street, Westminster, London, S. W.
- 1883 Jamme, George,
Dayton, Tennessee, U.S.A.
- 1884 Jameson, John,
Akenside Hill, Newcastle-on-Tyne.
- 1889 Jamieson, James Fleming Fyfe,
*c/o Brown, Fleming & Murray, 163 West George Street,
Glasgow.*
- 1889 Jaques, Wm. Hy.,
Bethlehem Iron Company, South Bethlehem, Pa., U.S.A.
- 1877 Jeans, J. S.,
28 Victoria Street, London, S. W.
- 1879 Jefferies, J. R.,
Ipswich.

Elected Member	
1888	Jeffreys, Edward, <i>Hawkshill, Chapel Allerton, Leeds.</i>
1891	Jenkins, Alfred, <i>Wharnccliffe, Penarth, near Cardiff.</i>
1876	Jenkins, A. T., <i>Masbro' Boiler Works, Rotherham.</i>
1872	Jenkins, James G., <i>33 Renfield Street, Glasgow.</i>
1869	*Jenkins, Sir J. J., <i>The Grange, Swansea.</i>
1869	*Jenkins, William, <i>Consett Iron Works, Consett, County Durham.</i>
1874	Jenkins, William, <i>Dowlais Iron Works, Dowlais.</i>
1885	Jenks, Isaac James, <i>Cleveland Iron Works, Wolverhampton.</i>
1887	Jenks, Walter, <i>Minerva Works, Horseley Fields, Wolverhampton.</i>
1882	Jennings, Charles, <i>17 Croft Terrace, Jarrow-on-Tyne.</i>
1875	Jennings, James, <i>3 Ilminster Gardens, Lavender Hill, Clapham Junction, London, S.W.</i>
1890	Johnson, Herbert Alfred, <i>Bradford Iron Works, Manchester.</i>
1871	Johnson, J. Thewlis, <i>Bradford Iron Works, Manchester.</i>
1873	Johnson, Walter, <i>Exchange Buildings, Middlesbrough.</i>
1875	Johnson, W. H., <i>26 Lever Street, Manchester.</i>
1880	Johnston, James, <i>7 Market Place, Macclesfield.</i>
1881	Jonas, Joseph, <i>Continental Steel Works, Sheffield.</i>
1882	Jones, Alfred W., <i>Dashwood House, New Broad Street, London, E.C.</i>
1870	Jones, Benjamin, <i>Dowlais Iron Works, Dowlais, Glamorganshire.</i>
1886	Jones, Daniel Robert, <i>Dowlais Iron Works, Dowlais, Glamorganshire.</i>
1881	Jones, Edwin, <i>141 Cannon Street, London, E.C.</i>
1874	Jones, Ephraim A., <i>Ayrton Rolling Mills, Middlesbrough.</i>
1892	Jones, Greville Tyndall, <i>Clarence Iron Works, Middlesbrough.</i>

Elected Member	
1890	Jones, Henry, <i>Oakwood Grange, Rotherham.</i>
1890	Jones, James, <i>Brooklands, Swansea.</i>
1884	Jones, James Cecil, <i>Rhymney Iron Works, South Wales.</i>
1870	Jones, John, <i>Dowlais Iron Works, Dowlais.</i>
1881	Jones, Joseph, <i>Corrugated Iron Works, Wolverhampton.</i>
1881	Jones, Wm. E., <i>141 Cannon Street, London, E.C.</i>
1889	Jopling, Thomas, <i>Otis Iron and Steel Coy., Cleveland, Ohio, U.S.A.</i>
1889	Jordan, Albert Edward, <i>Monkbridge Iron Works, Leeds.</i>
1889	Jordan, Andrew Jackson, <i>6 Baker's Hill, Sheffield.</i>
1874	Jordan, Sampson, <i>5 Rue Viète, Quartier Monceaux, Paris.</i>
1875	Jordan, Thomas, <i>Dunkirk Iron Works, West Bromwich.</i>
1878	Jouraffsky, Demetrius, <i>St. Petersburg, Russia.</i>
1889	Jowitt, Charles Albert Renny, <i>Scotia Works, Sheffield.</i>
1891	Jungermann, C., <i>Vulcan Shipbuilding Works, Stettin, Germany.</i>
1879	Justice, Philip S., <i>55 Chancery Lane, London, W.C.</i>
1888	Kearsley, George, <i>British Iron and Implement Works, Ripon.</i>
1888	Keay, Ernest Charles, <i>Corporation Street, Birmingham.</i>
1885	Keen, Arthur, <i>London Works, Smethwick, near Birmingham.</i>
1888	Keighley, George, <i>Bankhouse Iron Works, Burnley.</i>
1874	Kellett, William, <i>24 King Street, Wigan.</i>
1886	Kendall, J. Dixon, <i>Roper Street, Whitehaven.</i>
1884	Kennard, H. J., <i>20 Hyde Park Terrace, London, W.</i>

Elected Member	
1883	Kennedy, Professor A., F.R.S., 19 <i>Little Queen Street, London, S.W.</i>
1888	Kennedy, Myles, <i>Hill Fort, Ulverston.</i>
1890	Kennedy, Wm., 28 <i>Royal Exchange Square, Glasgow.</i>
1881	Kenrick, Geo. H., <i>Whelstone, Somerset Road, Edgbaston, Birmingham.</i>
1883	Kerpely, A. Ritter von, <i>Buda-Pesth, Hungary.</i>
1886	Kerr, Andrew, <i>Ardeer, N.B.</i>
1891	Kerr, John, 101 <i>Leadenhall Street, London, E.C.</i>
1884	Kidner, John, <i>Islip House, Thrapston.</i>
1884	King, John William, <i>Sheffield Steel and Iron Works, Sheffield.</i>
1891	Kirchhoff, Charles, 96 to 102 <i>Reade Street, New York, U.S.A.</i>
1869	*Kirk, Henry, <i>Workington.</i>
1874	Kirk, Peter, <i>Mossbay Iron Works, Workington.</i>
1869	*Kirkconel, John F., <i>Furnace House, Cleator Moor, viâ Carnforth, Cumberland.</i>
1888	Kirkhouse, Edward Godwin, <i>Conselt Iron Works, Blackhill, County Durham.</i>
1883	Kitching, A. E., <i>Ayton Firs, Great Ayton, R.S.O., Yorkshire.</i>
1881	Kitching, John, <i>Branksome Hall, Darlington.</i>
1889	Kitson, Albert Ernest, <i>Monkbridge Iron Works, Leeds.</i>
1885	Kitson, Fredk. James, <i>Monkbridge Iron Works, Leeds.</i>
1869	*Kitson, Sir James, Bart., M.P., <i>Monkbridge Iron Works, Leeds.</i>
1879	Koch, Charles, <i>St. Chamond, Loire, France.</i>
1878	Koch, Walter E., <i>Spang Iron and Steel Co., Sharpsburg, Pa., U.S.A.</i>
1888	Koch, Francis, 19 <i>Gr^{de} Komiouschennaia, St. Petersburg, Russia.</i>
1884	Koehler, Henry, <i>Bochum, Westphalia, Germany.</i>
1875	Kolokoltzoff, Rear-Admiral, <i>Oboukoff Steel Works, St. Petersburg, Russia.</i>

Elected
Member

- 1889 Korb, Fridolin,
Bohler Bros. & Co., Styrian Steel Works, Sheffield.
- 1883 Krautner, Adolf,
Vorderberg, Styria, Austria.
- 1886 Kriete, Henry C.,
17 Metropolitan Block, Chicago, U.S.A.
- 1891 Krupp, F. A.,
Essen, Rhenish Prussia.
- 1880 Kupelwieser, Paul,
Wilkowitz, Austria.
-
- 1874 Laing, James,
Sunderland.
- 1892 Lambe, George Craig,
Craig Bank, Workington, Cumberland.
- 1883 Lancaster, Jno.,
Anfield House, Leamington.
- 1874 Lancaster, Joshua,
Talladeya Iron and Steel Company, Alabama, U.S.A.
- 1872 Landale, Andrew,
Cornely Park Place, Dunfermline.
- 1881 Langdon, Wm.,
Huelva, Spain.
- 1890 Lash, Horace W.,
Pittsburgh, U.S.A.
- 1885 Latinis, Victor,
Charleroi, Marcinelle, Belgium.
- 1888 Launder, George,
Edgar-Thomson Steel Works, Pittsburgh, U.S.A.
- 1876 Lawson, Arthur T.,
Hope Foundry, Leeds.
- 1869 *Laybourne, Richard,
Isca Foundry, Newport, Monmouthshire.
- 1887 Ledingham, L. Napier,
Wallace Works, Sheffield.
- 1887 Lee, Arthur,
Bessemer Road, Attercliffe, Sheffield.
- 1889 Lee, Henry,
Sedgley Park, Prestwich, Lancashire.
- 1887 Lees, John Bayley,
Oaklands, Church Lane, Handsworth.
- 1889 Lees, Samuel,
Parkbridge, Ashton-under-Lyne.
- 1879 Leigh, Joseph,
Tabley House, Knutsford.

Elected Member	
1888	Leishman, John G. A., <i>Lewis Block, Pittsburgh, U.S.A.</i>
1882	Lennard, J. Milner, <i>Middlesbrough-on-Tees.</i>
1878	Lester, John Nicholls, <i>Bradford Iron Works, Walsall.</i>
1887	Lever, Ellis, <i>Tan-y-Bryn, Colwyn Bay, N. Wales.</i>
1870	Leveson-Gower, Hon. E. F., M.P., <i>14 South Audley Street, London, W.</i>
1870	Levick, Frederick, <i>Cornhill Chambers, White Lion Court, Cornhill, London, E.C.</i>
1881	Lewis, Henry, <i>Kingshurst, Sandwell, Handsworth, Birmingham.</i>
1891	Lewis, Herbert Clark, <i>Aberdare, Monmouthshire.</i>
1869	*Lewis, Henry Watkin, <i>Llwyn-yr-eas, Abercanaid, near Merthyr Tydfil.</i>
1891	Lewis, James F., <i>23 Park Place, New York, U.S.A.</i>
1882	Lewis, William B., <i>8 Victoria Chambers, Westminster, London, S.W.</i>
1871	Lewis, Sir William Thomas, <i>Mardy, Aberdare.</i>
1886	Liddell, G. H., <i>Morseby Hall, Whitehaven.</i>
1889	Liddelow, Charles, <i>12 Victoria Street, Westminster, London, S.W.</i>
1888	Lindberg, Carl Oson, <i>Laxå, Sweden.</i>
1874	Lindheim, W. von, <i>Lugeck, 3, Vienna.</i>
1874	Lindow, Jonas, <i>Ehen Hall, near Carnforth.</i>
1881	Lindsay, Thos. S., <i>31 Poultry, London, E.C.</i>
1883	Linnell, Arthur, <i>The New Cransley Iron and Steel Company, Ltd., Kettering.</i>
1882	Lithman, Jos. E., <i>14 Fenchurch Street, London, E.C.</i>
1881	Little, George, <i>Messrs. Platt Brothers, Oldham.</i>
1880	Livesey, James, <i>Broad Street Avenue, Blomfield Street, London, E.C.</i>
1880	Ljungberg, E. J., <i>Falun, Sweden.</i>
1876	Llewelyn, F. W., <i>Shelton Bar Iron Works, Stoke-on-Trent.</i>

Elected Member	
1869	*Lloyd, Francis H., <i>Stave Hill, Lichfield.</i>
1869	*Lloyd, Samuel, <i>The Farm, Sparkbrook, Birmingham.</i>
1880	Lloyd, W. E., <i>303 Ickneild Port Road, Birmingham.</i>
1874	Lloyd, William Henry, <i>Hall Green, Wednesbury.</i>
1869	*Lloyd, Wilson, <i>Mywood House, Wednesbury.</i>
1891	Lodge, Joseph, <i>South Pittsburgh, Tennessee, U.S.A.</i>
1875	Lones, Edward, <i>Iron and Tin-plate Works, Lydney, Gloucestershire.</i>
1883	Lones, Jabez, <i>Lansdowne, South Road, Smethwick.</i>
1875	Long, A. de Lande, <i>Stockton-on-Tees.</i>
1871	Longridge, R. B., <i>Yew Tree House, Tabley, near Knutsford.</i>
1875	Longridge, R. C., <i>Kibrie, Knutsford.</i>
1869	*Longsdon, Alfred, <i>75 Old Broad Street, London, E.C.</i>
1890	Loomis, Burdett, <i>Hartford, Conn., U.S.A.</i>
1889	Lopes, George, <i>Engineer's Office, L., B., and S. C. Ry., London Bridge, S.E.</i>
1881	Louis, Henry, <i>9 D'Almeida Street, Singapore.</i>
1874	Lowe, John E., <i>2 Lawrence Pountney Hill, London, E.C.</i>
1875	Lowood, John Grayson, <i>Ganister Works, Sheffield.</i>
1888	Lucas, Richard Norman, <i>8 Featherstone Buildings, High Holborn, London, W.C.</i>
1876	Lueg, Carl, <i>Gütehoffnungshütte, Oberhausen, Westphalia, Germany.</i>
1882	Lueg, C. H., <i>Düsseldorf, Germany.</i>
1876	Lürmann, Fritz W., <i>Osnabrück, Germany.</i>
1884	Lyon, Alfred C., <i>Albrighton Hall, Wolverhampton.</i>
1888	Lysaght, Wm. Royse, <i>Swan Garden Iron Works, Wolverhampton.</i>

Elected Member	
1890	Macfarlane, Walter, <i>Garnochside, Glengarnock, near Glasgow.</i>
1884	Macalpine, G. W., <i>Parkside, Accrington.</i>
1884	Macarthy, G. E., <i>Ashfield House, Newcastle-on-Tyne.</i>
1880	Macco, H., <i>Siegen, Germany.</i>
1889	Macdonald, Kenneth, <i>Rose Hill, Whitehaven.</i>
1879	MacLaran, Rowland, <i>Dafin Tin Plate Works, Gilfig, Llanelly.</i>
1890	MacIaren, John Finlay, <i>Eglinton Foundry, Glasgow.</i>
1888	MacIaren, Robert, Jun., <i>Eglinton Foundry, Glasgow.</i>
1882	Maclean, Andrew H., <i>8 Hughenden Terrace, Kelvinside, Glasgow.</i>
1888	MacLellan, George S., <i>Clutha Iron Works, Glasgow.</i>
1886	MacLellan, Wm. Turner, <i>Clutha Iron Works, Glasgow.</i>
1873	MacLennan, Joseph, <i>Bilbao, Spain.</i>
1874	Macpherson, George, <i>Wednesbury Oak Iron Works, Tipton.</i>
1881	Macnee, Daniel, <i>2 Westminster Chambers, London, S. W.</i>
1879	Magery, Jules, <i>Rothe Erde, Aix-la-Chapelle.</i>
1890	Magery, Maurice, <i>Rothe Erde, Aix-la-Chapelle.</i>
1891	Mahon, Capt. Reginald Henry, <i>Cassipore, Calcutta.</i>
1879	Main, Robert, <i>Ardeer Iron Works, Stevenston, Ayrshire.</i>
1891	Malcolm, Samuel, <i>8 Portland Terrace, Newcastle-on-Tyne.</i>
1879	Malo, Alberto, <i>Guanajuato, Mexico.</i>
1889	Mallaband, John, <i>Woodleigh, Broomgrove Road, Sheffield.</i>
1890	M'Anally, Peter, <i>Midvale Steel Coy., Philadelphia, U.S.A.</i>
1888	Mannaberg, Max, <i>Frodingham Iron Works, near Doncaster.</i>
1890	Markham, Chas. Paxton, <i>Broad Oaks Iron Works, Chesterfield.</i>

Elected
Member

- 1885 Marley, J. E.,
Hebburn-on-Tyne.
- 1879 Maroquin, A.,
Couillet, near Charleroi, Belgium.
- 1887 Marsden, Benjn.,
Bolt and Nut Works, London Road, Manchester.
- 1873 Marsh, T. E. M.,
Engineer's Office, Hawthorn House, Bath.
- 1881 Marsh, W. Sutcliffe,
190 St. Helens Road, Swansea, Glamorganshire.
- 1878 Marshall, David,
Glasgow Tube Works, Glasgow.
- 1889 Marshall, Francis Carr,
Messrs. Hawthorn, Leslie, & Co., Newcastle-on-Tyne.
- 1880 Marshall, F. H.,
Ormesby Iron Works, Middlesbrough.
- 1890 Marston, Charles,
The Oaks, Wolverhampton.
- 1883 Marston, S.,
North-Eastern Steel Works, Middlesbrough.
- 1876 Martélet, M.,
56 Rue de Provence, Paris.
- 1879 Martell, B.,
2 White Lion Court, Cornhill, London, E.C.
- 1882 Marten, Edward B.,
Stourbridge.
- 1869 *Marten, Henry John,
The Birches, Codsall, near Wolverhampton.
- 1871 Martin, Edward P.,
Dowlais, Glamorganshire.
- 1883 Martin, R.,
Drumman Isaf, Llansamlet, Swansea.
- 1887 Marvel, William D.,
68 William Street, New York, U.S.A.
- 1891 Mason, James Francis,
Eynsham Hall, Witney, Oxon.
- 1878 Massenez, Joseph,
19 Parkstrasse, Wiesbaden, Germany.
- 1880 Massey, W. H.,
Twynford, Berks.
- 1892 Mather, Andrew John,
Bolling Hall, Bradford, Yorks.
- 1887 Mather, William,
Salford Iron Works, Manchester.
- 1889 Matheson, Ewing,
Farnley Iron Works, near Leeds.
- 1886 Mathieson, Thomas A.,
East Campbell Street, Glasgow.

Elected Member	
1885	Mathieu, Jean A., 51 <i>Moffat Block, Detroit, Michigan, U.S.A.</i>
1888	Matthews, John, <i>R. & W. Hawthorn, Leslie & Co., Forth Banks, Newcastle-on-Tyne.</i>
1874	Maw, William Henry, 36 <i>Bedford Street, Strand, London, W.C.</i>
1881	Maybery, Joseph, <i>Oldcastle Tin Plate Works, Llanelly.</i>
1888	Maybury, Edward, <i>Perseverance Iron Works, Pendleton, Manchester.</i>
1887	Mayer, Ernest, 66 <i>Boulevard Malesherbes, Paris.</i>
1874	Maynard, George W., 31 <i>Nassau Street, New York, U.S.A.</i>
1869	*Maynard, H. N., 7 <i>Westminster Chambers, London, S.W.</i>
1890	McClure, Samuel, <i>Sharon, Penn., U.S.A.</i>
1884	McCorkindale, Dr. D., <i>Glydesdale Iron and Steel Works, Mossend, Glasgow.</i>
1884	McCowan, Wm., <i>Roseneath, Whitehaven.</i>
1890	McCullum, John, <i>Frodingham, Doncaster.</i>
1886	McDonald, Wm., <i>Carlisle Villa, Carlisle Road, Manor Park, Essex.</i>
1883	McDonnell, Alexander, <i>The Cedars, Norwood Green, Southall.</i>
1891	McKillop, John, <i>Pulo Bani, Singapore, Straits Settlements.</i>
1891	McKnight, Wharton, <i>Anchor Foundry and Machine Works, Pittsburgh, Pa., U.S.A.</i>
1892	McLachlan, Thomas, 45 <i>Linden Gardens, Bayswater, London, W.</i>
1889	McMurtry, George Gibson, <i>Apollo Iron and Steel Company, Pittsburgh, U.S.A.</i>
1891	McNeil, Chas., Jun., 270 <i>West Scotland Street, Glasgow.</i>
1871	McClelland, Andrew S., 115 <i>St. Vincent Street, Glasgow.</i>
1890	McConway, William, 48th <i>Street, A.V.R.R., Pittsburgh, U.S.A.</i>
1889	McCreath, Andrew S., <i>Sidney Coal Company, Harrisburg, Pa., U.S.A.</i>
1878	McCreath, James, 208 <i>St. Vincent Street, Glasgow.</i>

Elected
Member

- 1888 M'Gowan, Wm.,
Whitehaven, Cumberland.
- 1880 Melling, Samuel,
Ince Forge, Wigan.
- 1886 Melling, Thomas,
Ince Forge, Wigan.
- 1883 Melnhof, Baron F. Mayr von,
Operngasse, 4, Vienna, Austria.
- 1890 Merritt, Louis Gilbert,
Lockport, New York, U.S.A.
- 1878 Merritt, W. H.,
34 St. George Street, Toronto, Canada.
- 1891 Middleton, Thomas Biscoe,
*Bengal Iron and Steel Company, Limited, Barrakur,
India.*
- 1886 Miller, J. Ritchie,
2 Somerset Place, Glasgow.
- 1886 Miller, Thomas,
London Road Foundry, Edinburgh.
- 1882 Miller, John F.,
Vulcan Foundry, Coatbridge, N.B.
- 1889 Millward, George Anthony,
41 Church Hill, Wednesbury.
- 1875 Milner, Walter,
Whitecross Wire Works, Warrington.
- 1891 Milton, James Taylor,
2 White Lion Court, Cornhill, London, E.C.
- 1890 Mischke, Carl,
Weitburg, Prussia.
- 1870 Mitchell, Charles,
Elswick Works, Newcastle-on-Tyne.
- 1891 Mitchell, Joseph,
Mining Offices, Barnsley.
- 1891 Mitchell, Joseph,
Sydney, New South Wales.
- 1884 Molineaux, William,
Capponfield Iron Works, Bilston.
- 1870 Monks, Frederick,
Walton Old Hall, near Warrington.
- 1873 Moon, Richard, Jun.,
Penyvael, Llanymynech, near Oswestry.
- 1881 Moore, Alfred,
Fitzroy Works, Euston Road, London, N.W.
- 1876 Moore, Arthur C.,
*Fred. Braby & Co., Ltd., Galvanised Iron Works, Deptford,
S.E.*
- 1882 Moore, William,
Spring Vale Furnaces, Ettingshall, near Wolverhampton.

Elected Member	
1875	Morel, Ernest, <i>Tilleul Rolling Mills, Maubeuge, France.</i>
1880	Morgan, C. H., <i>Worcester, Mass., U.S.A.</i>
1882	Morgan, Thomas R., <i>Alliance, Ohio, U.S.A.</i>
1888	Morgan, Septimus Vaughan, <i>42 Cannon Street, London, E.C.</i>
1882	Morris, Claude John, <i>Edge Mount, Altrincham.</i>
1883	Morris, Wm. H., <i>400 Chestnut Street, Philadelphia, U.S.A.</i>
1873	Morton, E. H. (care of P. F. Morton), <i>Hook House, near Winchfield, Hants.</i>
1879	Morton, James, <i>Manor Park, Blairhill, Coatbridge, N.B.</i>
1889	Moses, Edmund Bamford, <i>Cwm Avon, Glamorganshire.</i>
1875	Mosley, Col. Paget, <i>27 St. James' Square, London, S.W.</i>
1882	Mottram, Richard, <i>Knott Mill Iron Works, Manchester.</i>
1886	Mudd, Thomas, <i>Hartlepool.</i>
1890	Muir, Alfred, <i>Sherbourne Street, Manchester.</i>
1883	Muirhead, Wm., <i>The Lanarkshire Steel Company, Limited, Motherwell, N.B.</i>
1881	Müller, R. W. Maxwell, <i>Scarboro' and Whitby Railway, Scarborough.</i>
1889	Müller, Thomas Neil, <i>Messrs. Müller & Co., Exchange Buildings, Middlesbrough.</i>
1890	Mungall, James, <i>Fod Bank, Dunfermline, N.B.</i>
1885	Murisier, Oscar, <i>Acieries d'Alexandrowsky, St. Petersburg.</i>
1890	Musgrave, Walter M., <i>Bolton.</i>
1888	Myers, W. Beswick, <i>14 Victoria Street, London, S.W.</i>
1884	Nash, H. V. B., <i>c/o T. B. Coddington & Co., 27 Cliff Street, New York, U.S.A.</i>

Elected Member	
1889	Naylor, John William, <i>Wellington Foundry, Leeds.</i>
1890	Needham, Christopher Thomas, <i>13 Cannon Street, Manchester.</i>
1888	Needham, John, <i>13 Cannon Street, Manchester.</i>
1890	Needham, Joseph, <i>Baker's Hill, Sheffield.</i>
1869	*Neesham, George, <i>Middlesbrough.</i>
1875	Neilson, George, <i>Summerlee Iron Works, Coatbridge, N.B.</i>
1874	Neilson, James, <i>Mossend Works, Holytown Station, N.B.</i>
1869	*Neilson, John, <i>Summerlee, Coatbridge, N.B.</i>
1880	Neilson, Walter, <i>Clyde Bridge Steel Coy., Cambuslang, N.B.</i>
1888	Nettlefold, John Sutton, <i>Castle Works, Tydu, Newport, Monmouthshire.</i>
1887	Newbigging, Thomas, <i>Manchester.</i>
1890	Newton, Joseph, <i>Verona Villa, Endcliffe Rise Road, Sheffield.</i>
1890	Nice, Alfred Slater, <i>Carlton Hall, Newmarket.</i>
1891	Nicholas, Evan, <i>Merthyr Tydfil, South Wales.</i>
1888	Nicholls, Thomas, <i>90 High Street, Redcar.</i>
1888	Nicholson, Henry, <i>Albert Chambers, Albert Square, Manchester.</i>
1889	Nicholson, James Percival <i>Bowling Iron Works, Bradford, Yorks.</i>
1891	Noble, Henry A., <i>Great Western Iron and Steel Coy., Seattle, Washington State, U.S.A.</i>
1885	Noble, James, <i>Grosvenor Terrace, Linthorpe Road, Middlesbrough.</i>
1877	Norbury, William Edward, <i>Knott Mill Iron Works, Manchester.</i>
1873	Nordenfelt, Thorsten, <i>c/o E. Ristori, 9 Victoria Street, London, S.W.</i>
1869	*Norris, W. G., <i>Coalbrookdale, Salop.</i>
1890	North, Colonel John Thomas, <i>Woolpack Buildings, Gracechurch Street, E.C.</i>

Elected Member	
1880	Nursey, Perry F., 161 <i>Fleet Street, London, E.C.</i>
1889	Oakes, Gerard R. <i>Riddings, Alfreton.</i>
1869	*Oakes, Thomas H., <i>Alfreton Works, Alfreton, Derbyshire.</i>
1892	Odena, Antonio de Uruburo, <i>Bilbao, Spain.</i>
1883	Ogilvie, A. G., 4 <i>Great George Street, London, S.W.</i>
1883	Ogle, Percy Jno., 4 <i>Bishopsgate Street Within, London, E.C.</i>
1875	Ogle, Richard, 4 <i>St. Ann's Square, Manchester.</i>
1884	Oliver, D. B., 114 <i>First Avenue, Pittsburgh, Pennsylvania, U.S.A.</i>
1884	Oliver, H. W., Jun., 114 <i>First Avenue, Pittsburgh, Pennsylvania, U.S.A.</i>
1881	Onions, Edward, <i>Clarence Iron Works, Middlesbrough.</i>
1890	Openshaw, William Henry, <i>Billiter Square Buildings, London, E.C.</i>
1887	Ordenez, Col. D. Salvador, <i>Ordnance Works, Trubia, Spain.</i>
1872	Ormiston, J. W., <i>Douglas Gardens, Uddingston, near Glasgow.</i>
1892	Osborn, Samuel, <i>Clyde Steel and Iron Works, Sheffield.</i>
1890	Oser, Johann, <i>Hegelgasse, Vienna, Austria.</i>
1890	Osmond, F., 83 <i>Boulevard de Courcelles, Paris.</i>
1889	Otis, Charles Augustus, <i>Otis Iron and Steel Company, Cleveland, Ohio, U.S.A.</i>
1884	Otto, Dr. C., 20 <i>Rue Froissart, Brussels.</i>
1889	Owen, David, <i>Morriston, R.S.O., Glamorganshire.</i>
1888	Owen, Hubert James, 38 <i>Arcade Chambers, St. Mary's Gate, Manchester.</i>
1881	Packer, Geo. S., <i>John Brown & Coy., Limited, Atlas Steel and Iron Works, Sheffield.</i>

Elected Member	
1878	Page, John, <i>Penkridge, near Stafford.</i>
1875	Paget, Berkeley, <i>2 Lawrence Pountney Hill, London, E.C.</i>
1882	Palechondhuri, B., <i>Moheshgurig Factory, Krishnugsher, Bengal, India.</i>
1869	*Palmer, Sir Charles M., Bart., M.P., <i>Jarrow Iron Works, Newcastle-on-Tyne.</i>
1884	Panton, W. H., <i>Dorman, Long & Co., Middlesbrough.</i>
1873	Paris, William, <i>Glasgow Iron Works, Glasgow.</i>
1874	Parke, G. H., <i>Barrow Rolling Stock Works, Barrow-in-Furness.</i>
1879	Parker, Wm., <i>Electric Welding Co., 6 Great George Street, London, S.W.</i>
1882	Parkes, Ebenezer, <i>Atlas Iron Works, West Bromwich.</i>
1882	Parkes, Henry P., <i>Tipton Chain, Cable, and Anchor Works, Tipton.</i>
1889	Parkes, John Israel, <i>Eagle Works, Smethwick.</i>
1875	Parkyn, William J., <i>Engineering Works, Dukinfield, near Manchester.</i>
1881	Parratt, W., <i>58 Lyndhurst Road, Peckham, London, S.E.</i>
1869	*Parry, John, <i>Ebbw Vale Iron Works, Newport, Monmouthshire.</i>
1888	Pasquier, Pierre, <i>Forges de Wendel, Hayange, Lorraine, Germany.</i>
1892	Passelecq, Alberic-Vital, <i>Boulevard Dolez, 17, Mons, Belgium.</i>
1879	Pastor, G., <i>Jemeppe, near Liege, Belgium.</i>
1878	Patchett, George, <i>Manor Road, Halifax.</i>
1882	Patchett, James, <i>Shropshire Iron Works, Hadley, Wellington, Salop.</i>
1886	Paterson, T. S., <i>Motherwell, N.B.</i>
1884	Paterson, John, <i>Belle Isle Place, Workington.</i>
1887	Paton, John, <i>Pontypool, Mon.</i>
1890	Patrick, A. C., <i>Johnstone, Renfrewshire, N.B.</i>
1886	Patterson, Anthony, <i>Dowlais, Glamorganshire.</i>

Elected Member	
1869	Pattinson, John, 75 <i>Side, Newcastle-on-Tyne.</i>
1874	Pattison, John, <i>Naples, Italy.</i>
1892	Pattison, John Alfred, <i>Naples, Italy.</i>
1881	Paul, Fred. Wilson, <i>Hallside Steel Works, Newton, Glasgow.</i>
1890	Peacock, Ralph, <i>Gorton Foundry, Gorton, near Manchester.</i>
1878	Peake, John Nash, <i>The Tileries, Tunstall, Staffordshire.</i>
1889	Pearce, Sir William George, Bart., <i>Cardell, Wemyss Bay, N.B.</i>
1885	Pearn, Frank, <i>West Gorton, Manchester.</i>
1877	Pears, George, <i>Wilton House, Wilton-le-Wear, Darlington.</i>
1890	Pearson, Cecil Hope, <i>The Blaenavon Coy., Ltd., 86 Cannon Street, London, E.C.</i>
1883	Pearson, Jos. H., <i>Handsworth, near Birmingham.</i>
1875	Pearson, Peter, <i>Dunkirk Iron Works, West Bromwich.</i>
1873	Pearson, Thos. H., <i>Dallam Forge Company, Wigan.</i>
1883	Pearson, W. G., <i>97 Cannon Street, London, E.C.</i>
1884	Pease, Arthur, <i>Darlington.</i>
1888	Pease, John Francis, <i>Pierremont, Darlington.</i>
1887	Pease, Joseph Albert, <i>Darlington.</i>
1882	Pease, Henry Fell, M.P., <i>Darlington.</i>
1869	*Pease, Sir Joseph W., Bart., M.P., <i>Hutton Hall, Guisbro', Yorks.</i>
1875	Pechin, Edmund C., <i>Roanoke, Va., U.S.A.</i>
1890	Peech, Henry, <i>Phoenix Steel Works, Sheffield.</i>
1883	Peech, W. H., <i>Phoenix Bessemer Steel Works, Ickles, near Sheffield.</i>
1885	Peile, Wm., <i>Cartgate, Hensingham, Whitehaven.</i>
1880	Pendred, Vaughan, <i>33 Norfolk Street, Strand, London, W.C.</i>

Elected
Member

- 1881 Pepper, Joseph E.,
Clarence Iron Works, Leeds.
- 1884 Percy, Thomas McLeod,
Wigan Coal and Iron Coy.'s Works, Wigan.
- 1890 Perkins, James Watt,
42 Snow Hill, Holborn, London, E.C.
- 1890 Perkins, Simon, junior,
Sharon, Penn., U.S.A.
- 1879 Pernot, Chas.,
Ingenieur, Brigneris (Rhône), France.
- 1889 Peters, Theodor,
14 Wichmannstrasse, Berlin.
- 1885 Petherick, John,
Consett Iron Works, Blackhill, Co. Durham.
- 1873 Petin, Jean J. Hippolyte,
Rue Mont Grand, 24, Marseilles, France.
- 1874 Peto, Samuel Arthur,
Plumbago Crucible Works, Battersea, London, S.W.
- 1890 Petre, Axel E.,
Midvale Steel Company, Philadelphia, U.S.A.
- 1890 Pfeifer, Ferdinand,
Centralstrasse, 4, Leipzig, Germany.
- 1890 Philip, Arnold,
43 Onslow Road, Richmond, Surrey.
- 1890 Phillips, Chas. D.,
Emlyn Engineering Works, Newport, Monmouthshire.
- 1890 Phillips, John Wm.,
23 College Hill, London, E.C.
- 1883 Phipps, Henry, Jun.,
Edgar-Thomson Works, Pittsburgh, Pa., U.S.A.
- 1892 Pickford, Joseph James,
30 Oak Hill Road, Nether Edge, Sheffield.
- 1874 Piedbœuf, Gustave,
Aix-la-Chapelle, Prussia.
- 1884 Pierce, J. J.,
Sharpsville, Pennsylvania, U.S.A.
- 1886 Pilkington, Herbert,
Apedale, near Newcastle, Staffordshire.
- 1887 Ping, Francis,
The Avenue, Linthorpe, Middlesbrough.
- 1876 Pink, Richard,
6 Sedars Strasse, Hanover, Germany.
- 1883 Platt, Jas. E.,
Messrs. Platt Brothers, Oldham.
- 1882 Platt, James,
Atlas Iron Works, Gloucester.
- 1873 Platt, Samuel R.,
Werneth Park, Oldham.

Elected Member	
1889	Pochin, Henry D., <i>Bodnant Hall, Eghoysbach, R.S.O., Denbighshire.</i>
1881	Poensgen, Carl, <i>Düsseldorf, Germany.</i>
1881	Poensgen, Rudolph, <i>Düsseldorf, Germany.</i>
1890	Polonceau, Gustave Ernest, <i>Boulevard de la Gare, 41, Paris.</i>
1881	Ponthière, Honoré, <i>Louvain University, Belgium.</i>
1887	Pope, Samuel, <i>Tinsley House, Tinsley, Sheffield.</i>
1885	Potter, E. C., <i>1161 Rookery, Chicago, U.S.A.</i>
1872	Potts, John Thorpe, <i>1001 Chestnut Street, Philadelphia, U.S.A.</i>
1879	Pourcel, Alexandre, <i>2 Square du Roule, Paris.</i>
1890	Powell, Horatio Gibbs, <i>Wood Villa, Tettenhall Wood, Wolverhampton.</i>
1890	Powell, John, <i>Millbrook Iron and Steel Works, Landore, S. Wales.</i>
1883	Powell, W. H., <i>Ebbw Vale, Monmouthshire.</i>
1889	Preston, Fredk. Walter, <i>The Poplars, Burton Latimer, Kettering.</i>
1878	Price, John, <i>6 Osborne Villas, Jesmond, Newcastle-on-Tyne.</i>
1874	Price, Joseph, Jun., <i>Brunswick Foundry, Liverpool.</i>
1891	Priestman, Albert, <i>Priestman Bros., 73a Queen Victoria Street, London, E.C.</i>
1890	Procter, John R., <i>Frankfort, Kentucky, U.S.A.</i>
1890	Pugh, Chas. Hy., <i>Whitworth Works, Rea Street South, Birmingham.</i>
1890	Purves, David, <i>123 Liverpool Road, Birkdale, Southport.</i>
1869	*Putnam, William, <i>Darlington Forge, Darlington.</i>
1884	Putnam, Thomas, <i>Darlington Forge, Darlington.</i>
1881	Pye-Smith, Arnold, <i>32 Queen Victoria Street, London, E.C.</i>

Elected Member	
1885	Radcliffe, Francis, 233 <i>Burridge Road, Plumstead, London, S.E.</i>
1890	Radcliffe, William, <i>Camden House, Collegiate Crescent, Sheffield.</i>
1879	Radford, R. H., 15 <i>St. James's Row, Sheffield.</i>
1874	Ramage, John, <i>Beckenham, Kent.</i>
1869	*Ramsbottom, John, <i>Fernhill, Alderly Edge, Cheshire.</i>
1869	*Ramsden, Sir James, <i>Barrow-in-Furness.</i>
1869	*Ramsden, W. G., 13 <i>Tower Chambers, Liverpool.</i>
1890	Rankin, Matthew, <i>Cleddens, N.B.</i>
1879	Ransome, Allen, <i>Stanley Works, King's Road, Chelsea, London, S.W.</i>
1887	Ransome, Frederick, 42 <i>Melbourne Grove, East Dulwich, London, S.E.</i>
1874	Rapier, Richard C., 9 <i>Westminster Chambers, London, S.W.</i>
1888	Rapley, Frederick Harvey, c/o <i>Taste & Carlton, 63 Queen Victoria Street, London, E.C.</i>
1869	*Ratliffe, George, 7a <i>Laurence Pountney Hill, Cannon Street, London, E.C.</i>
1892	Rawdon, William John, <i>Elm Villa, Soho Road, Handsworth.</i>
1874	Ray, Edmund, <i>Lindal Moor Mines, Ulverston.</i>
1871	Reay, Thomas M., <i>Spennymoor, County Durham.</i>
1882	Reay, Thomas P., <i>Airedale Foundry, Leeds.</i>
1870	Reed, Sir E. J., M.P., <i>Broadway Chambers, Westminster, London, S.W.</i>
1891	Rees, Robert Thomas, <i>Glandare, Aberdare, Monmouthshire.</i>
1880	Reichwald, A., 9 <i>New Broad Street, London, E.C.</i>
1889	Reimers, E., 19 <i>Schonsbeckerstrasse, Magdeburg-Buckau, Germany.</i>
1880	Remaury, M., 56 bis, <i>Rue de Chateaundun, Paris.</i>
1883	Rendel, W. Stuart, 8 <i>Great George Street, Westminster, London, S.W.</i>
1890	Renshaw, William Robert, <i>Kids Grove, Staffordshire.</i>

Elected Member	
1878	Renton, Benjamin Mann, <i>Savile Street, Sheffield.</i>
1886	Resimont, Armand, <i>Valenciennes, Nord, France.</i>
1890	Retz, Comte G. de, <i>49 Rue de Grenelle, Saint Germain, Paris.</i>
1885	Reynolds, George B., <i>Manager, Warora Colliery, Warora, C. P., India.</i>
1881	Reynolds, Thos., <i>99 Cromwell Road, South Kensington, London, S.W.</i>
1887	Rhodes, George W., <i>The Cottage, Victoria Park, Manchester.</i>
1889	Richards, David, <i>Hillside, Ammanford, Carmarthenshire.</i>
1892	Richards, Edgar Josiah, <i>Barrow Hematite Steel Works, Barrow-in-Furness.</i>
1869	*Richards, Edwin, <i>Ty Craig, Caerleon, Monmouthshire.</i>
1869	*Richards, E. Windsor, <i>Loxmoor House, Loxmoor, Yorkshire.</i>
1869	*Richards, Josiah J., <i>Atlas Steel Works, Sheffield.</i>
1869	*Richards, Job, <i>Westminster Chambers, Corporation Street, Birmingham.</i>
1869	*Richards, L., <i>West Cumberland Iron and Steel Co., Ltd., Workington.</i>
1882	Richardson, George, <i>98 Westbourne Terrace, London, W.</i>
1869	*Richardson, Joseph, <i>Stockton-on-Tees.</i>
1872	Richardson, T. G., <i>Killamarsh Forge, Chesterfield.</i>
1869	*Richardson, W., <i>Platt Brothers' Works, Oldham.</i>
1881	Richter, Carl, <i>Generaldirektor der Vereinigten Königs & Laurahütte, Behrenstrasse, 44, Berlin, Germany.</i>
1889	Ridgely, William Barrett, <i>Springfield Iron Company, Springfield, Illinois, U.S.A.</i>
1869	*Ridley, J. Cartmell, <i>3 Summerhill Grove, Newcastle-on-Tyne.</i>
1877	Ridley, T. D., <i>Coatham, Redcar.</i>
1883	Ridsdale, C. H., <i>Hutton Grange, Guisbrough, Yorkshire.</i>
1873	Riley, Edward, <i>2 City Road, Finsbury Square, London, E.C.</i>

Elected Member	
1874	Riley, James, 23 <i>Royal Exchange Square, Glasgow.</i>
1873	Ripley, Hugh, <i>Bowling Dye Works, Bradford, Yorks.</i>
1891	Ritchie, George, <i>Parkhead Forge, Glasgow.</i>
1882	Ritson, John H. R., <i>Aberdulais, near Neath, S. Wales.</i>
1881	Rixon, A. W., 10 <i>Austin Friars, London, E.C.</i>
1891	Roberts, D. Evan, <i>Dowlais Iron Works, Dowlais, Glamorganshire.</i>
1888	Roberts, James, <i>The Leasowes, West Bromwich.</i>
1891	Roberts, Thomas Henry, <i>Witton Lane Iron Works, West Bromwich.</i>
1891	Roberts, William, <i>Tipton Green Furnaces, Staffordshire.</i>
1881	Roberts-Austen, W. Chandler, C.B., F.R.S., <i>Royal Mint, London, E.</i>
1885	Robertson, Daniel A. W., <i>The Metropolitan Coal Coy., Helensburgh, N. S. Wales.</i>
1885	Robertson, Sir Henry B., <i>Palé, Corwen, South Wales.</i>
1869	*Robinson, John, <i>Westwood Hall, Leek, Staffordshire.</i>
1888	Robinson, John Fred., <i>Atlas Works, Springburn, Glasgow.</i>
1881	Robinson, R., <i>Howlish Hall, Bishop Auckland.</i>
1890	Robinson, Richard, <i>Home Cottage, Crabtree, Pitsmoor, Sheffield.</i>
1881	Robinson, Sydney J., <i>Brightside Steel Works, Sheffield.</i>
1879	Robinson, T. N., <i>Railway Works, Rochdale.</i>
1891	Robinson, Theo. W., <i>Colorado Fuel and Iron Coy., Pueblo, Colorado, U.S.A.</i>
1870	Robson, Edward, <i>Leatham House, Redcar.</i>
1884	Robson, Neil, 1 <i>Dixon Street, Glasgow.</i>
1880	Rocour, G., 18 <i>Avenue Rogier, Liège, Belgium.</i>
1889	Roe, Pearce, 10 <i>Foulser Road, Upper Tooting, London, S.W.</i>
1883	Roepper, C. W., <i>Solid Steel Company, Alliance, Ohio, U.S.A.</i>

Elected
Member

- 1873 Rogé, Xavier,
Pont-à-Mousson, Meurthe, France.
- 1878 Rogers, John Henry,
South Wales Iron Works, Llanelly.
- 1870 Rogerson, John,
Croxdale Hall, Durham.
- 1890 Rogerson, John E.,
Ordnance Steel Works, Wolsingham.
- 1890 Rogerson, Wm. E.,
Croxdale Hall, Durham.
- 1889 Rognetta, Colonel Francois Benoit,
153, Via Torino, Rome, Italy.
- 1885 Rollason, James,
Bromford Wire Mills, Erdington, Birmingham.
- 1891 Roper, Robert,
Banner Cross, Sheffield.
- 1869 *Round, Benjamin,
Hange Furnaces, Tividale, Tipton.
- 1890 Rowley, Brooke,
Abram Pulman & Sons, Halifax.
- 1875 Rummens, Chas.,
8 Oldfield Terrace, Acton Vale, London, W.
- 1870 Rummens, Francis,
54 Warrington Crescent, Maida Vale, London, W.
- 1889 Rummens, Francis William,
Belmont Place, Portswood, Southampton.
- 1888 Ruscoe, John,
Hyde, near Manchester.
- 1877 Russell, Emil,
Disconto Gesellschaft, Berlin.
- 1882 Russell, John,
8 Victoria Chambers, Westminster, London, S. W.
- 1883 Russell, W.,
Pather Iron Works, Wishaw, N.B.
- 1885 Russell, Robert,
Coltness Iron Works, Newmains, N.B.
- 1886 Russell, George,
Summerlee Iron Works, Coatbridge, N.B.
- 1890 Ryder, George,
Turner Bridge Iron Works, Tongue, near Bolton.
- 1890 Ryland, Fred.,
A. Kenrick & Sons, Limited, West Bromwich.
- 1890 Ryland, William,
Rye Lodge, Nether Edge, Sheffield.

Elected Member	
1877	Sacré, Alfred Louis, <i>60 Queen Victoria Street, London, E.C.</i>
1887	St. Oswald, Lord, <i>Nostell Priory, Wakefield.</i>
1890	Salmon, William, <i>Miteside, Holmrook, viâ Carnforth.</i>
1890	Salter, George, <i>Springfield, West Bromwich.</i>
1880	Salter, Moses, <i>10 St. George's Square, Worcester.</i>
1889	Sampson, Richard H., <i>Pontardulais, South Wales.</i>
1886	Samuel, James, <i>Glengarnock, N.B.</i>
1869	*Samuelson, Sir Bernhard, Bart., M.P., <i>56 Prince's Gate, South Kensington, London, S.W.</i>
1885	Samuelson, Francis A. E., <i>Sockburn Hall, Darlington.</i>
1887	Sandahl, Carl J., <i>Trimsaran, S. Wales.</i>
1892	Saniter, Ernest Henry, <i>11 Newmarket Street, Wigan.</i>
1890	Sankey, John Wm., <i>Wintersdorf, Wolverhampton.</i>
1877	Sartoris, Herbert, <i>Kettering Furnaces, Kettering.</i>
1890	Sauer, Franz, <i>N. B. Allen & Co., 110 Cannon Street, London, E.C.</i>
1887	Saunders, James, <i>86 Darlington Street, Wolverhampton.</i>
1889	Sauvée, Albert, <i>22 Parliament Street, London, S.W.</i>
1875	Sawrey, John S., <i>20 Bucklersbury, London, E.C.</i>
1890	Scarf, Fredk., <i>Bromford Iron Works, West Bromwich.</i>
1872	Scuttergood, J., <i>Stour Valley Works, Spon Lane, Birmingham.</i>
1883	Schleghtendal, F., <i>Duisburg, Germany.</i>
1882	Schlink, Joseph, <i>Friedrich-Wilhelmshütte, Mulheim-on-the-Ruhr, Germany.</i>
1891	Schmitz, Albert, <i>Bahnhofstrasse, 20, Essen, Germany.</i>
1890	Schneider, Chas. P. Eugene, <i>Creusot, France.</i>
1876	Schneider, Henry, <i>Creusot, France.</i>

Elected Member	
1881	Schott, Robert, <i>Dannemora Steel Works, Sheffield.</i>
1888	Schrodter, E., <i>Verein Deutscher Eisenhüttenleute, Düsseldorf, Germany.</i>
1884	Schroller, Wm. C. P. H., <i>16 Baldry Gardens, Streatham Common, London, S.W.</i>
1885	Schultz, George, <i>Botolph House, Eastcheap, London, E.C.</i>
1884	Schulz, Gustav, <i>8 Friedrichstrasse, Bochum, Westphalia, Germany.</i>
1892	Schumacher, Casper, <i>Brewer Schumacher & Co., Kalk, near Cologne, Germany.</i>
1890	Schwarz, Cecil Ritter von, <i>c/o H. von Schaez, Generalstabs Chef der 13 Armee Division Wien, Austria.</i>
1881	Scott, Ernest, <i>Close Works, Newcastle-on-Tyne.</i>
1882	Scott, Ralph G., <i>Monkbridge Iron Works, Leeds.</i>
1878	Scott, William Henry, <i>Newcastle-on-Tyne.</i>
1888	Scoular, George, <i>5 Vale View, St. Bees, Carnforth.</i>
1882	Seaman, Fred., <i>Oak Mount, Adelaide Road, Brincliffe, Sheffield.</i>
1880	Seddon, R. B., <i>Wigan.</i>
1883	Seebeck, Leopold, <i>120 Cannon Street, London, E.C.</i>
1877	Seeborn, Henry, <i>22 Courtfield Gardens, South Kensington, London, W.</i>
1889	Seelhoff, Robert, <i>Witten, Westphalia, Germany.</i>
1874	Sellers, William, <i>1600 Hamilton Street, Philadelphia, U.S.A.</i>
1890	Senhouse, Humphrey P., <i>The Fitz, Cockermouth.</i>
1881	Senior, George, <i>Pond's Forge, Sheffield.</i>
1879	Sepulchre, A., <i>Aulnoye-lez-Berlaimont, France.</i>
1878	Sepulchre, François, <i>Vezin, Belgium.</i>
1891	Service, Andrew Graham, <i>27 St. Vincent Place, Glasgow.</i>
1880	Shakell, W. H., <i>George Yard, Upper Thames Street, London, E.C.</i>

Elected Member	
1890	Shanks, William, <i>Union Iron Works, Johnstone, N.B.</i>
1886	Share, Geo. W., <i>72 King William Street, London, E.C.</i>
1869	*Sharp, Henry, <i>Samuel Fox & Co., Ltd., Stocksbridge Works, near Sheffield.</i>
1883	Sharp, John, <i>5 St. Bernard's Crescent, Edinburgh.</i>
1890	Sharp, Thomas Budworth, <i>Tangye's Works, Birmingham.</i>
1872	Shaw, William, Sen., <i>Wellington Steel Foundry, Middlesbrough.</i>
1892	Sheard, Robert, <i>Spurr, Inman & Co., Ltd., Wakefield.</i>
1890	Sheffield, R. S., <i>Upper Eglinton Road, Woolwich, S.E.</i>
1888	Sheldon, John George, <i>Newbiggin, Richmond, Yorks.</i>
1891	Shenton, James, <i>Greenfield House, Hyde, near Manchester.</i>
1869	*Shield, Clifton, <i>Reform Club, Pall Mall, London, S.W.</i>
1883	Shipman, John W., <i>Attercliffe Steel Wire Mills, Sheffield.</i>
1889	Siddell, George, <i>Roewood, Crabtree, Pitsmoor, Sheffield.</i>
1878	Siemens, Alexander, <i>12 Queen Anne's Gate, Westminster, London, S.W.</i>
1884	Siemens, Frederick, <i>12 Queen Anne's Gate, Westminster, London, S.W.</i>
1883	Simmons, Charles, <i>Barrow Hematite Steel Co., Ltd., Barrow-in-Furness.</i>
1874	Simon, Henry, <i>20 Mount Street, Manchester.</i>
1883	Simons, David, <i>Dorset Place, Stow Hill, Newport, Mon.</i>
1880	Simpson, F. F., <i>Park Lane Iron Works, Oldbury.</i>
1892	Simpson, Harcourt Tasker, <i>Montgomery House, Sharrow, Sheffield.</i>
1877	Simpson, J. B., <i>Hedgefield House, Blaydon-on-Tyne.</i>
1888	Simpson, Joseph, <i>Moss Close, Walsall.</i>
1874	Simpson, J. S., <i>Harrington Iron Works, Harrington, Cumberland.</i>
1876	Simpson, William W., <i>Oswaldtwistle Collieries, near Accrington.</i>

Elected Member	
1884	Simpson, Henry Charles. <i>Horsehay, near Wellington, Shropshire.</i>
1886	Simpson, Robert, <i>Harrington, Cumberland.</i>
1889	Slater, James, <i>Bescot Hill, Walsall.</i>
1874	Smith, Charles, <i>c/o Dr. Gilbert, F.R.S., Harpenden, St. Albans.</i>
1881	Smith, C. Weston, <i>Langland Hall, Mumbles, South Wales.</i>
1882	Smith, Fred., <i>Caledonia Works, Halifax, Yorkshire.</i>
1882	Smith, G. Jackson, <i>Haslewood, Ranmoor, Sheffield.</i>
1889	Smith, Henry John, <i>Newmains, N.B.</i>
1880	Smith, Jno. Jos., <i>Southwood House, Eltham, Kent.</i>
1882	Smith, Joseph H., <i>Summerhill, Kingswinford, near Dudley.</i>
1869	*Smith, Josiah T., <i>Rhine Hill, Stratford-on-Avon.</i>
1874	Smith, Robert, <i>Castle Hill, Sheffield.</i>
1889	Smith, Samuel, <i>Monway Steel Works, Wednesbury.</i>
1876	Smith, Thomas Taylor, <i>Gosforth, Newcastle-on-Tyne.</i>
1885	Smith, Watson, <i>University College, Gower Street, London, W.</i>
1884	Smith, W. A., <i>Heyford Iron Works, near Weedon, Northampton.</i>
1877	Smith, W. Ford, <i>Gresley Iron Works, Manchester.</i>
1876	Smyth, Samuel Richard, <i>The Steel and Iron Coy., Stowe, near Weedon.</i>
1869	*Snelus, G. J., F.R.S., <i>Ennerdale Hall, Frizington, viâ Carnforth.</i>
1890	Sochor, Baron Friedrich R., <i>Fische Gasse, Vienna, Austria.</i>
1884	Soldenhoff, Richard de, <i>71 St. Mary's Street, Cardiff.</i>
1884	Somers, Walter, <i>Hayword Forge, Birmingham.</i>
1884	Sorby, T. W., <i>Storthfield, Sheffield.</i>
1886	Sorby, Henry C., F.R.S., <i>Broomfield, Sheffield.</i>

Elected Member	
1885	Sotomayor, Major F. Alvarez, <i>Ordinance Works, Trubia, Spain.</i>
1889	Sparrow, Henry, <i>Himley, Dudley.</i>
1891	Spaulding, H. W., <i>Manufacturing Coy., Grinnell, Iowa, U.S.A.</i>
1889	Spencer, Charles, <i>West Stockton Iron Works, Stockton-on-Tees.</i>
1869	*Spencer, John, <i>Phoenix Works, Coatbridge, N.B.</i>
1888	Spencer, John, <i>Globe Tube Works, Wednesbury.</i>
1879	Spencer, J. W., <i>Millfield House, Newburn-on-Tyne.</i>
1869	*Spencer, Thomas, <i>The Grove, Ryton, Blaydon-on-Tyne.</i>
1880	Squire, Edw. L., <i>Coalbrookdale Iron Works, Shropshire.</i>
1888	Squire, Lionel R. Littler, <i>30 St. John's Wood Park, London, N.W.</i>
1890	Squire, Wm. Stevens, Ph.D., <i>Clarendon House, St. John's Wood Park, London, N.W.</i>
1878	Stanger, William Harry, <i>Testing Works, Broadway, Westminster, London, S.W.</i>
1890	Stanley, Hon. E. Lyulph, <i>18 Mansfield Street, Cavendish Square, London, W.</i>
1881	Stanley, John W., <i>The Laboratory, Tondy, Bridgend, Glamorganshire.</i>
1873	Stead, J. E., <i>5 Zetland Road, Middlesbrough.</i>
1886	Steel, Henry, Jun., <i>Phoenix Steel Works, Ickles, Sheffield.</i>
1890	Steel, James, <i>Boroughfield, Colinton Road, Edinburgh.</i>
1886	Steel, Wm., <i>Phoenix Steel Works, Ickles, Sheffield.</i>
1890	Steele, Robert, <i>6 Gracechurch Street, London, E.C.</i>
1873	Steer, Edward, <i>Castle Works, Tydu, near Newport, Monmouthshire.</i>
1877	Sterne, Louis, <i>2 Victoria Mansions, Westminster, London, S.W.</i>
1880	Steven, Thos., <i>Milton Iron Works, Glasgow.</i>
1875	Stevens, Warwick Allan, <i>Darlington Works, Southwark Bridge Road, London, S.E.</i>
1869	*Stevenson, John, <i>Acklam Iron Works, Middlesbrough.</i>

Elected Member	
1891	Stevenson, John Lester, <i>Lewis Block, Pittsburgh, Pa., U.S.A.</i>
1873	Stewart, Andrew, <i>41 Oswald Street, Glasgow.</i>
1883	Stewart, Peter, <i>Tharsis Sulphur and Copper Co., Glasgow.</i>
1876	Stoddart, Charles John, <i>Parkgate Iron Works, Rotherham.</i>
1872	Stoker, F. W., <i>Easton & Anderson Co. (Ld.), Erith Iron Works, Erith, Kent.</i>
1880	Storey, Sir Thomas, <i>Lancaster.</i>
1884	Storey, Edgar, <i>1 Rumford Place, Liverpool.</i>
1888	Storey, Thomas E., <i>Kids Grove, Staffordshire.</i>
1887	Storey, Wm. John Patrickson, <i>Preswylfa, Rhyl, N. Wales.</i>
1888	Storr, Frederick, <i>21 The Groves, Chester.</i>
1886	Storr, Walter W., <i>Messrs. Bolckow, Vaughan & Co., Middlesbrough.</i>
1885	Straker, Herbert, <i>Thornaby Iron Works, Stockton-on-Tees.</i>
1879	Strang, J. H., <i>Lochburn Iron Works, Glasgow.</i>
1883	Strange, A. J., <i>Malakoff House, Abergavenny.</i>
1876	Strick, George Henry, <i>Amman Iron Works, Swansea.</i>
1880	Strick, Jno., <i>Bar Hill, Madeley, Staffordshire.</i>
1881	Stubbs, Frederick, <i>Edgegate, Osborne Road, Sheffield.</i>
1885	Sturrock, David, <i>Carntyne Iron Co., Glasgow.</i>
1872	Summers, James W., <i>Globe Iron Works, Stalybridge.</i>
1890	Summers, John, <i>Globe Iron Works, Stalybridge.</i>
1872	Sumner, William, <i>Brazenose Street, Manchester.</i>
1876	Sutcliffe, F. John Ramsbottom, <i>Low Moor Iron Works, Bradford, Yorks.</i>
1892	Sutherland, David Alexander, <i>28 Victoria Street, London, S. W.</i>
1892	Sutcliffe, Samuel, <i>Mount Terrace, Mostyn, North Wales.</i>

Elected
Member

- 1890 Svedelius, A. G.,
Uddeholm Works, Sweden.
- 1873 Swan, Edward W.,
Middlesbrough.
- 1873 Swan, Herbert A.,
Middlesbrough.
- 1874 Swan, Henry F.,
Beaufront Castle, Hexham.
- 1869 *Swan, John G.,
Cargo Fleet Iron Works, Middlesbrough.
- 1869 *Swindell, J. E.,
Cradley Iron Works, Stourbridge.
- 1890 Sykes, Ezra,
Glenfield, Marsh, Huddersfield.
- 1881 Sykes, Robert,
Acres House, Stalybridge.
- 1879 Tait, James,
Raisby Hill Lime Works, Cozhoe, County Durham.
- 1890 Tannett, John Croysdale,
Rose Mount, Chapeltown, Leeds.
- 1869 Tate, John,
Workington Hematite Iron and Steel Co. (Ld.), Workington.
- 1875 Tatham, Thomas,
102 Corporation Street, Manchester.
- 1880 Taylor, James,
Shirecliffe Cottage, Shirecliffe Road, Sheffield.
- 1888 Taylor, Joseph Samuel,
Derwent Foundry, Birmingham.
- 1876 Taylor, T. A. O.,
Clarence Iron Works, Leeds.
- 1887 Taylor, James,
Park House, Queen's Road, Oldham.
- 1890 Taylor, Joseph Garside,
Thorndene, Tupton House Road, Sheffield.
- 1892 Taylor, William J.,
High Bridge, New Jersey, U.S.A.
- 1887 Tench, Wm. R.,
Hamilton Iron Works, Garston, near Liverpool.
- 1879 Tennant, Sir Charles, Bart.,
St. Vincent Street, Glasgow.
- 1890 Thackray, George Edward,
Cambria Iron Co., Johnstown, Pa., U.S.A.
- 1885 Thackray, Wm., Jun.,
7 The Avenue, Sunderland.

Elected Member	
1875	Thielen, Alex., <i>Phoenix Iron Works, Ruhrort, Rhenish Prussia.</i>
1890	Thomas, Francis Teherne, <i>Meirion Cottage, Aberdare.</i>
1888	Thomas, James Lewis, <i>Bryn Awel, Aberdare.</i>
1892	Thomas, John, <i>Plusissa, Llangennech, South Wales.</i>
1889	Thomas, John Glyn, <i>Llangennech, South Wales.</i>
1888	Thomas, Richard, <i>Birchill's Iron Works, near Walsall.</i>
1881	Thomas, R. B., <i>The Moorlands, Lydney, Gloucestershire.</i>
1878	Thomas, William, <i>Bryn Awel, Aberdare.</i>
1888	Thomas, William, <i>109 Tettenhall Road, Wolverhampton.</i>
1878	Thomas, William Henry, <i>15 Parliament Street, London, S.W.</i>
1882	Thomlinson, Wm., <i>Seaton Carew, near West Hartlepool.</i>
1882	Thompson, Sir Henry M. Meysey, Bart., <i>Kirby Hall, York.</i>
1882	Thompson, James, <i>Singleton Park, Kendal.</i>
1889	Thompson, Philip, <i>Thompson & Co., Zetland Buildings, Middlesbrough.</i>
1886	Thompson, Robert, <i>Fulwell West House, Sunderland.</i>
1883	Thompson, S. Jno., <i>Muchall Grove, Wolverhampton.</i>
1891	Thompson, Wilson, <i>Gryffe House, Bridge of Weir, N.B.</i>
1879	Thomson, Charles, <i>Calder Iron Works, Coatbridge, N.B.</i>
1873	Thomson, Grahame H., <i>129 Trongate, Glasgow.</i>
1882	Thomson, James R., <i>Clyde Bank, Dumbartonshire.</i>
1869	*Thomson, J. M., <i>Calder Iron Works, Glasgow.</i>
1878	Thomson, John, <i>Eston Mines, near Middlesbro'-on-Tees.</i>
1881	Thwaites, Edward H., <i>Vulcan Iron Works, Bradford, Yorks.</i>
1891	Tilley, Albert, <i>Wolverhampton Road, Walsall.</i>

Elected
Member

- 1890 Tinn, Cecil Godfrey,
Mill House, Pontnewynydd, South Wales.
- 1871 Tinn, Joseph,
Begbrook, Frenchay, near Bristol.
- 1874 Todd, Hadden W.,
St. Helens, Lancashire.
- 1884 Tolmie, A. D.,
166 Buchanan Street, Glasgow.
- 1889 Tompkin, John Benjamin,
Newhall Steel Works, Sheffield.
- 1891 Torbock, Joseph,
Middlesbrough-on-Tees.
- 1885 Tonks, Edwin,
Holly Cottage, West Smethwick.
- 1890 Torrens, Gerard,
Cromwell Road, South Kensington, London, W.
- 1870 Tosh, E. G.,
North Lonsdale Iron and Steel Company, Ulverston.
- 1883 Tozer, Wm.,
13 Lawson Road, Sheffield.
- 1883 Trasenster, Paul,
Boulevard Frère-Orban, 4, Liège, Belgium.
- 1889 Triponé, Emile,
36 bis Boulevard d'Argenson, Neuilly, Paris.
- 1881 Trubshaw, Ernest,
Western Tin Plate Works, Llanelly, South Wales.
- 1880 Tucker, A. E.,
35 Paradise Street, Birmingham.
- 1892 Turley, Theodore,
Anchor Tube Company, Gas Street, Birmingham.
- 1886 Turner, Thomas,
Shelton Iron and Steel Works, Stoke-on-Trent.
- 1887 Turner, Thomas,
Mason Science College, Birmingham.
- 1884 Turton, Geo.,
Patent Buffer Steel and File Works, Sheffield.
- 1883 Turton, John,
Vulcan Forge and Rolling Mills, Sheffield.
- 1885 Tweedie, Jas. A.,
12 St. Andrew Square, Edinburgh.
- 1889 Twynam, Thomas,
7 Marlborough Terrace, Bedford Park, London, W.
- 1889 Tylden-Wright, Charles,
Ashley Grove, Worksop.
- 1879 Upton, Douglas,
Stockton Malleable Iron Company, Stockton-on-Tees.

Elected Member	
1874	Valentine, Charles J., 20 <i>Victoria Street, Workington.</i>
1875	Valton, Ferdinand, 166 <i>Faubourg St. Honoré, Paris.</i>
1873	Vaughan, Cedric, <i>Hodbarrow Mines, Millom, Cumberland.</i>
1885	Verdié, E., 91 <i>Rue Jouffroy, Paris.</i>
1892	Verestchaguin, Nicolas, <i>Dobriansay Works, Perm, Prussia.</i>
1869	*Vickers, T. E., <i>River Don Works, Sheffield.</i>
1881	Vitoria, José Felix, <i>Bilbao, Spain.</i>
1883	Vivian, John, <i>Whitehaven.</i>
1891	Vosmaer, Alex., <i>Hâagsche Plateelbakkerij, "Rozenburg," Holland.</i>
1869	*Waddington, Joseph, <i>Iron Foundry, Barrow-in-Furness.</i>
1870	Wadham, Edward, <i>Millwood, Dalton-in-Furness.</i>
1890	Wadham, Walter Francis A., <i>Millwood, Dalton-in-Furness.</i>
1883	Wailles, J. W., <i>Monkland House, near Airdrie, N.B.</i>
1885	Wake, Henry H., <i>River Wear Commission, Sunderland.</i>
1890	Walker, Arthur Tannett, <i>Goodman Street Works, Leeds.</i>
1886	Walker, C. C., <i>Lilleshall Old Hall, near Newport, Shropshire.</i>
1875	Walker, John Scarisbrick, <i>Pagefield Iron Works, Wigan.</i>
1874	Walker, William, <i>Hawthorn House, Saltburn-by-the-Sea, Yorkshire.</i>
1888	Walker, William Edward, <i>Whitehaven.</i>
1888	Walker, William Huginn, Jun., <i>Wicker Iron Works, Sheffield.</i>
1889	Walker, William Rose, <i>Illinois Steel Co., South Chicago, U.S.A.</i>

Elected
Member

- 1887 Wallis, James J.,
10 *St. Swithin's Lane, London, E.C.*
- 1875 Walton, John P.,
Acomb, Hexham.
- 1878 Walton, Joseph,
Zetland Buildings, Middlesbrough.
- 1889 Walton, Joseph Pearson,
Campbell Street, Wishaw, N.B.
- 1890 Warburg, Frederick Elias,
8 *Porchester Terrace, Hyde Park, London, W.*
- 1869 *Ward, George,
Bearnett House, Wolverhampton.
- 1869 *Ward, Henry,
Priestfield Works, Wolverhampton.
- 1891 Wardale, John Dobson,
Redheugh Engine-Works, Gateshead-on-Tyne.
- 1878 Ware, Charles William,
37 *Grosvenor Place, Newcastle-on-Tyne.*
- 1888 Warrington, Henry James,
Berry Hill Farm, Stoke-on-Trent.
- 1889 Watt, John Landale Wilson,
East Elm, Radnor Park, near Dalmuir, N.B.
- 1890 Watts, Edmund Hannay,
Devonhurst, Chiswick.
- 1890 Wawn, Charles,
Patent Shaft Works, Wednesbury.
- 1876 Webb, F. W.,
Chester Place, Crewe.
- 1873 Webb, Henry,
Irwell Forge, Bury.
- 1872 Webb, Henry A.,
Church Street Chambers, Stourbridge.
- 1873 Wedekind, Hermann,
158 *Fenchurch Street, London, E.C.*
- 1878 Weeks, Joseph D.,
Pittsburgh, Pa., U.S.A.
- 1872 Weir, William,
Gartsherrie Iron Works, Coatbridge, N.B.
- 1878 Wellman, Samuel T.,
Wellman Iron and Steel Co., Thurlow, Pa., U.S.A.
- 1892 Wells, W. E.,
Elmwood, Mosbrough, near Rotherham.
- 1872 Wendel, Henri de,
Hayange, Lorraine, Germany.
- 1872 Wendel, Robert de,
Hayange, Lorraine, Germany.
- 1889 Western, Chas. Robert,
Broadway Chambers, London, S.W.

Elected Member	
1878	Westmacott, Percy, <i>Benwell Hill, Newcastle-on-Tyne.</i>
1892	Wheatcroft, Ernest, <i>117 Industry Road, Darnall, near Sheffield.</i>
1890	Wheeler, E. A., <i>Sharon, Penn., U.S.A.</i>
1871	Wheelock, Jerome, <i>Worcester, Mass., U.S.A.</i>
1883	While, Adolph S., <i>Chancery Lane Safe Deposit, Chancery Lane, London, W.C.</i>
1883	While, Charles, <i>Cocken Villa, Walney Road, Barrow.</i>
1879	While, J. M., <i>Whinsfield, Barrow-in-Furness.</i>
1883	Whipham, A. H., <i>Queen's Square, Middlesbrough.</i>
1883	White, Hy., <i>Derwent House, Gold Tops, Newport, Mon.</i>
1887	White, Henry, <i>Bridge Street, Worksop.</i>
1885	White, John Henry, <i>Derwent Works, Workington.</i>
1889	White, Maunsel, <i>Bethlehem Iron Company, Bethlehem, Pa., U.S.A.</i>
1889	White, William Henry, C.B., <i>Director of Naval Construction, The Admiralty, London, S.W.</i>
1873	Whitehead, John, <i>Pewortham Priory, Preston, Lancashire.</i>
1881	Whitehouse, Daniel, <i>Abercarn, Newport, Mon.</i>
1886	Whitelaw, Thomas, <i>Wellington Street, Glasgow.</i>
1886	Whiteley, Henry J., <i>Lane House, Ulverston.</i>
1870	Whitham, J., <i>Perseverance Iron Works, Leeds.</i>
1888	Whittle, John, <i>Yarra House, Chorley, Lancashire.</i>
1890	Whitwell, Joseph Fry, <i>Saltburn-by-the-Sea.</i>
1869	*Whitwell, William, <i>Thornaby Iron Works, Stockton-on-Tees.</i>
1890	Whitwell, William Fry, <i>Thornaby Iron Works, Stockton.</i>
1876	Wicksteed, Jos. Hartley (care of J. Buckton & Co.), <i>Well House Foundry, Leeds.</i>
1889	Widdop, Isaac, <i>Don Iron Works, Mexbrough, Yorks.</i>

Elected
Member

- 1881 Wigzell, Eustace,
Sowerby Bridge, Yorkshire.
- 1890 Wild, Frederick Charles,
Borussia Steel Works, Sheffield.
- 1888 Wilkinson, George W.,
Risca, Newport, Monmouthshire.
- 1882 Wilkinson, George,
Tividale Sheet Mills, Tipton.
- 1885 Wilkinson, George W.,
Whitehaven.
- 1888 Wilkinson, Thomas,
99 Burngreave Road, Sheffield.
- 1884 Willans, B.,
Barrow-in-Furness.
- 1878 Willans, John William,
Mawson Buildings, 28 Deansgate, Manchester.
- 1875 Williams, David,
Alyn Tinplate Works, Mold, North Wales.
- 1883 Williams, E. Leader,
Ship Canal Office, Manchester.
- 1880 Williams, Iltyd.,
Linthorpe Works, Middlesbrough.
- 1880 Williams, Israel,
Solway Hematite Iron Works, Maryport.
- 1889 Williams, James,
The Fields, Newport, Monmouthshire.
- 1880 Williams, John,
Rogerston House, Tydu, Newport, Monmouthshire.
- 1872 Williams, Nicholas,
Houlbarrow Mines, Millom, Cumberland.
- 1888 Williams, Penry,
Linthorpe Iron Works, Middlesbrough.
- 1889 Williams, Peter,
Brymbo Steel Works, Wrexham.
- 1869 *Williams, Richard,
Brunswick Iron Works, Wednesbury.
- 1872 Williams, R. Price,
32 Victoria Street, London, S.W.
- 1874 Williams, Robert,
Excelsior Iron Works, Wishaw, N.B.
- 1877 Williams, Wilfred,
Newhall Works, Birmingham.
- 1882 Williams, William,
Upper Forest Steel and Tinplate Works, Swansea.
- 1880 Williamson, R. H.,
Oakhurst, Cockermouth.
- 1873 Williamson, J. D.,
Cargo Fleet Iron Works, Middlesbrough.

Elected Members	
1877	Williamson, Richard, <i>Workington, Cumberland.</i>
1890	Willis, Thomas Wilkinson, <i>32 South Grove Road, Sheffield.</i>
1870	Willman, Charles, <i>Middlesbrough.</i>
1869	*Wilson, Alexander, <i>Cyclops Works, Sheffield.</i>
1884	Wilson, A. E., <i>85 Chancery Lane, London, W.C.</i>
1890	Wilson, George, <i>Broughton Grange, via Carlisle.</i>
1869	*Wilson, Isaac, <i>Nunthorpe Hall, Middlesbrough.</i>
1869	*Wilson, John Frederick, <i>Tees Iron Works, Middlesbrough.</i>
1886	Wilson, Robt. Theo., <i>Tees Iron Works, Middlesbrough.</i>
1891	Winder, Charles Aston, <i>Forton Lodge, Pilsmoor, Sheffield.</i>
1879	Wise, W. Lloyd, <i>46 Lincoln's Inn Fields, London, W.C.</i>
1884	Witherow, J. P., <i>Pittsburgh, U.S.A.</i>
1884	Withy, Henry, <i>Middleton Shipyard, West Hartlepool.</i>
1882	Wittgenstein, Karl, <i>I, Krugerstrasse, 18, Vienna.</i>
1881	Wolfenden, William, <i>Vulcan Steel Works, Barrow-in-Furness.</i>
1883	Wood, B. G., <i>Wardsend Steel Works, Sheffield.</i>
1874	Wood, Charles, <i>Tees Iron Works, Middlesbrough.</i>
1889	Wood, Edward, <i>Ocean Iron Works, Ordsal Lane, Manchester.</i>
1885	Wood, Edward M., <i>2 Westminster Chambers, London, S.W.</i>
1873	Wood, George R., <i>Fairfield, Bothwell, N.B.</i>
1871	Wood, John, <i>Troon, N.B.</i>
1892	Wood, John, <i>Barley Brook Foundry, Wigan.</i>
1890	Wood, Percy, <i>84 Christ Church Road, Streatham Hill, London, S.E.</i>
1885	Wood, Reginald N., <i>Bignall Hill Colliery, Stafford.</i>

Elected Member	
1889	Wood, Stuart, 400 Chestnut Street, Philadelphia, U.S.A.
1882	Woodall, John W., St. Nicholas House, Scarborough.
1879	Woodcock, H. B., Low Moor Iron Works, near Bradford, Yorks.
1888	Woodcock, Joshua, Laburnum Cottage, Low Moor, Yorks.
1889	Woodward, Wm. C., Biddulph Valley Iron Works, Stoke-on-Trent.
1889	Woolcock, Henry, Whitehaven.
1890	Worrall, W. E., 131 Corporation Road, Middlesbrough.
1883	Wotherspoon, Jno., Gartsherrie Cottage, Coatbridge, N.B.
1890	Wragg, John Downing, Swadlincote, Burton-on-Trent.
1876	Wraith, George Henry, Tudhoe Iron Works, Spennymoor.
1887	Wright, Albert Leslie, Butterley Hall, Alfreton.
1873	Wright, J. Roper, Elba Steel Works, Gower Road, near Swansea.
1887	Wrightson, Stephen, Carnforth Iron Works, Carnforth.
1872	Wrightson, Thomas, Teesdale Iron Works, Stockton-on-Tees.
1871	Würzburger, Philip, Creuznach, Rhenish Prussia.
1878	Wynne, Francis George, 37 Walbrook, London, E.C.
1883	Ybarra, Don José A. de, Ronda de Recoletos, 3, Madrid, Spain.
1883	Ybarra, Tomas de Z., Bilbao, Spain.
1881	Young, Edmund B., Salroyd, 21 Cambalt Road, Putney, London, S.W.
1880	Young, James, Salroyd, 21 Cambalt Road, Putney, London, S.W.
1890	Young, John, Easterhouse, Baillieston, N.B.
1886	Young, Robert, 20 Victoria Street, London, S.W.

ORDINARY MEMBERS.

Elected Member	
1892	Young, Septimus, 5 <i>Victoria Street, Westminster, S.W.</i>
1890	Younger, John, 20 <i>Cook Street, Glasgow.</i>
1889	Zabalburn, Ramon de Jaurequi y, <i>Bilbao, Spain.</i>
1882	Zeitz, Theodore, <i>St. Peter's Close, Sheffield.</i>









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